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ABSTRACT

This report is included in the Environmental Protection Agency's (EPA) environmental protection technology series which describes research performed to develop and demonstrate instrumentation, equipment and methodology. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards. Specific application techniques addressed include irrigation, overland flow and infiltration - percolation of industrial and municipal wastewater. Other sections of this report deal with wastewater and site characteristics, system design and operation, environmental effects, public health considerations, and cost evaluation. A bibliography and glossary of terms are included. (CS)

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Wastewater Treatment And Reuse By Land Application - Volume II

Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

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August 1973

WASTEWATER TREATMENT AND REUSE
BY LAND APPLICATION
VOLUME II

By

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ABSTRACT

A nationwide study was conducted of the current knowledge and techniques of land application of municipal treatment plant effluents and industrial wastewaters. Selected sites were visited and extensive literature reviews were made (annotated bibliography will be published separately).

Information and data were gathered on the many factors involved in system design and operation for the three major land application approaches: irrigation, overland flow, and infiltration-percolation. In addition, evaluations were made of environmental effects, public health considerations, and costs--areas in which limited data are available.

Irrigation is the most reliable land application technique with respect to long term use and removal of pollutants from the wastewater. It is sufficiently developed so that general design and operational guidelines can be prepared from current technology.

Overland flow was found to be an effective technique for industrial wastewater treatment. Further development is required to utilize its considerable potential for municipal wastewater treatment.

Infiltration-percolation is also a feasible method of land application. Criteria for site selection, groundwater control, and management techniques for high rate systems need further development.

This report is submitted in fulfillment of Contract 68-01-0741 by Metcalf & Eddy, Inc., Western Regional Office, under the sponsorship of the Environmental Protection Agency. Work was completed as of April 1973.

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SECTION I

CONCLUSIONS

Conclusions derived from this study of the present state-of-the-art of land application of wastewater are presented in four categories: (1) general, (2) irrigation, (3) overland flow, and (4) infiltration-percolation.

GENERAL

- Irrigation, overland flow, and infiltration-percolation are the three general approaches used for the land application of municipal and industrial wastewater.
- In actual practice, numerous modifications and combinations of land application techniques have proven successful.
- Factors to be considered in site selection for a land application system include both those involving economic and land use planning and such technical factors as soil type and drainability, topography, groundwater levels and quality, underlying geologic formations, wastewater characteristics, and pretreatment.
- Primary, secondary, and intermediate quality municipal effluents have all been applied successfully to the land. Industrial wastewaters from food processing, pulp and paper, dairy, tannery, and chemical plants, often with only screening as pretreatment, also have been applied successfully.
- Effective management and monitoring are fundamental requirements for the successful operation of land application systems.
- Land application systems, in many cases, have been started as an expedient, and available technology was not incorporated in the planned operation and management of the systems.

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- There is a paucity of quantitative information in the literature on the removal efficiencies of soil systems with respect to wastewater constituents.

IRRIGATION

- Irrigation of croplands, forest, and landscaping with wastewater, either by spraying, ridge and furrow, or flooding techniques, is developed sufficiently so that general design and operational guidelines can be outlined from currently available technology.

- Provided that municipal wastewaters are adequately disinfected, there are no indications of serious health hazards caused by spray irrigation.

- Irrigation is the most reliable land application approach evaluated on the basis of direct wastewater recycling, renovation, long term use, and minimization of adverse environmental effects.

OVERLAND FLOW

- Overland flow, or treatment by spray-runoff (also known as "grass filtration"), has been demonstrated to be an effective technique for industrial wastewater treatment. Further development is required to utilize its considerable potential for treatment of municipal wastewater.

- Overland flow has distinct advantages over irrigation for heavy, slightly permeable soils or rolling terrain.

- Nitrogen, suspended solids, and BOD removals are excellent, and adverse environmental effects appear to be minimal. Systems have not been in operation long enough to determine long term effects or expectant period of use.

INFILTRATION-PERCOLATION

- Infiltration-percolation is another feasible approach to land application of municipal or industrial wastewater, and several high rate systems have shown success.

- Criteria for site selection, groundwater control, and management techniques for high rate systems need further development.

Infiltration-percolation, when practiced as a land disposal approach, is less reliable than irrigation from the standpoint of wastewater renovation and long term use.

SECTION II

RECOMMENDATIONS

The following recommendations, which have been developed as a result of this study, are grouped into three categories: (1) implementation of land application projects, (2) development of standard practices, and (3) research needs.

IMPLEMENTATION OF LAND APPLICATION PROJECTS

- Land application approaches, where feasible, should be considered as alternatives in developing wastewater management plans.

- When evaluating land application approaches for treatment as compared to conventional or advanced waste treatment processes, factors such as economics, simplicity of operation, and degree of renovation should be considered as well as the potential water reuse and the best use to be made of the land.

- To gain public acceptance and support for land application projects, realistic implementation programs, including public relations, should be developed to accompany any planning activities for wastewater management.

DEVELOPMENT OF STANDARD PRACTICES

- General evaluation procedures for design and management of land application systems should be developed by the EPA to ensure successful system operations.

- The operation of many existing systems can be enhanced through analysis of successful practices at other locations, evaluation of the key factors important to management, and initiation of monitoring of water quality changes throughout the system.

- Design and operation practices in land application are so dependent on local conditions that a detailed design or operations manual would likely stifle, rather than advance, the state-of-the-art.

RESEARCH NEEDS

Although a great deal is known, many technical questions must be answered before wastewater renovation by land application can become a scientific undertaking. Research must be initiated to define the environmental interactions of soil, groundwater, air, and wastewater. The priorities for research by subject area, as established in this study, are presented on the following list.

General Application

- Climatic investigations should be undertaken to define simultaneously surface soil and ambient air temperatures for the United States. Such information would be useful in determining the annual period in which vegetation and active bacterial metabolism might be maintained by wastewater application.

- Virological investigations should be undertaken where municipal wastewater is applied by spraying. Aerosol drift and infectivity and survival of viruses in aerosols, on vegetation, and in soil need investigation.

Irrigation

- The long term effects on soils, groundwater, and crops of (1) salt accumulation and (2) buildups of trace elements and heavy metals should be defined.

- There are several large municipal wastewater irrigation systems that have been operating for 50 to 60 years, and these could be investigated for long term effects.

- Studies on the effects of irrigation on the environment, such as those underway at Pennsylvania State University and those planned for Muskegon, Michigan, should be continued.

- Additional studies should be conducted to determine if crops grown under wastewater irrigation differ substantially in quality from crops grown using fresh water irrigation and other sources of plant nutrients.

Overland Flow

- Research on the application of the overland flow technique to municipal wastewater such as that at Ada, Oklahoma, should be continued.

- Field studies should be conducted to evaluate cold weather effects when using overland flow for industrial and municipal wastewater.

- A correlation between BOD loading and treatment efficiency should be investigated for various climates, lengths of runoff travel, types of grasses, and field slopes.

- The mechanisms of nitrogen removal for overland flow should be studied. Removals resulting from crop uptake, denitrification, and ammonia volatilization should be quantified, with the objective of optimizing nitrogen removal.

- The applicability of using grasses, such as Italian rye and common bermuda grass, as cover crops under various climatic conditions should be investigated. Such grasses have proven successful for irrigation.

- The effects of harvesting and removing hay for various grasses on BOD removal efficiency should be investigated.

- The removal of phosphorus as affected by loading cycles, length of runoff travel, and type of grass should be investigated.

Infiltration-Percolation

- Operating procedures and conditions that are necessary for optimum nitrogen removal should be identified and documented.

- The effect of nitrification in the soil on BOD removal, TDS leaching, and the degree of subsequent denitrification should be documented by field investigations.

- Studies on the effect of vegetation on nitrification and denitrification in the soil should be continued.

- The removal efficiency for refractory organics should be determined for high rate loadings, and the health hazard of any such material reaching the groundwater should be investigated.

- Environmental effects, such as increased leaching of inorganic compounds and increased groundwater hardness, should be investigated for high rate systems underlain by limestone formations. High organic loadings will result in considerable carbon dioxide production which may dissolve significant quantities of calcium and magnesium as well as lower the pH.

SECTION III

INTRODUCTION

Current knowledge on land application of municipal and industrial wastewater has been gathered and is reported in two volumes. The purpose of this volume (Volume II) is to present detailed information on the engineering and design aspects of land application. It is intended as a compendium of current knowledge--not as a statement of design guidelines. The study was conducted by reviewing the literature, visiting selected sites (as detailed in Appendix A), and cooperating with the fact-finding effort performed by the American Public Works Association (APWA).

Separate sections are included on irrigation with municipal wastewater, infiltration-percolation of municipal wastewater, land application of industrial wastewater, climatic constraints on land application, cost evaluation, and land application potential. Specifically omitted from the study is the subject of land application of municipal or industrial waste sludge.

A condensed Summary Report, printed separately as Volume I, is intended to highlight the state-of-the-art for planners and managers. References cited by bracketed numbers in the text are listed in alphabetical order in Section X.

In this introductory section the stage is set for further discussions by presenting the history of and approaches to land application, the application techniques, important characteristics of wastewaters, and renovation mechanisms in the soil matrix.

HISTORICAL BACKGROUND

Land application of sewage effluents began long before the complex technology of today's treatment systems was developed. The simplest and most logical disposal method for man was to put his sewage in the ground by burying it in trenches or pits.

With the recent concern for zero discharge of pollutants, land application of wastewater is being examined again. An investigation of systems operated in the past as well as those continuing to the present may offer insights on land application.

European Practice

Wastewater application to the land was practiced in Athens in the B.C. period [80]. Use of effluent for a beneficial purpose was reported in the sixteenth century in Germany [25]. The application of municipal wastes was used there for irrigation purposes on farmland. From that beginning, through the nineteenth century, the application of sewage effluents to farmland was practiced in continental Europe and England. The use of sewage effluent for irrigation was the simplest method of treatment and disposal available at that time. The benefits from the natural fertilizers were also recognized. The early sewage farms were fairly successful in their operation, provided the management was competent. When farms were poorly managed, crops failed, odors were present, and complaints were numerous. Some of the better farms are listed in Table 1; not many records are available on poorly operated farms. It is assumed that they failed and were abandoned.

The crops grown on the sewage farms were usually grains, grasses, root vegetables, and corn. Some farmers used the effluent on fields planted with all types of fruits and vegetables with success. The yield from a sewage farm would commonly be at least twice that of a conventional farm in the same area.

Most of the farms had underdrains that conveyed the excess water to nearby streams. The purity of the stream was apparently not affected by the added water, illustrating the treatment given the water by its passage through soil.

The practice of sewage farming spread to South Africa, Australia, and Mexico as those areas were colonized, and it continues today.

American Practice

The practice of land disposal of sewage effluents began in the United States in the late nineteenth century. The first land disposal projects, also listed in Table 1, were developed only for irrigation purposes. Groundwater recharge projects were not started until the early twentieth century in the semiarid regions of California and Utah.

Table 1. Historical Data on Sewage Farming

Date	Location	Description	Wetted area, acres	Flow, mgd	Average loading, in./wk	Reference
	Non-United States					
1559	Bunzlau, Germany	Sewage farm	--	--	--	25
1861	Croydon-Beddington, England	Sewage farm	420	4.5	2.8	81
1864	South Norwood, England	Sewage farm	152	0.7	1.2	81
1869	Berlin, Germany	Sewage farm	27,250^{a}	150^{a}	1.4	81
1875	Leamington Springs, England	Sewage farm	400	0.8	0.5	96
1880	Birmingham, England	Sewage farm	1,200	22	4.7	96
1893	Melbourne, Australia	Irrigation	10,376^{b}	50^{b}	1.2	76
	Melbourne, Australia	Overland flow	3,472^{b}	70^{b}	5.2	76
1902	Mexico City, Mexico	Irrigation	112,000^{b}	570^{b}	1.3	--
1923	Paris, France	Irrigation	12,600	120	2.5	81
1928	Cape Town, South Africa	Irrigation	--	--	--	21
	United States					
1872	Augusta, Maine^{c}	Irrigation	3	0.007	0.6	97
1880	Pullman, Illinois^{c}	Irrigation	40	1.85	12.0	97
1881	Cheyenne, Wyoming	Irrigation	1,330^{d}	7.0^{d}	1.3	--
1887	Pasadena, California	Irrigation	300	--	--	81
1895	San Antonio, Texas	Irrigation	4,000^{a}	20^{a}	1.3	81
1896	Salt Lake City, Utah	Irrigation	180	4	5.7	97
1912	Bakersfield, California	Irrigation	2,400^{d}	11.3^{d}	1.2	--
1928	Vineland, New Jersey	Irrigation	14	0.8	14.7	83

a. Data for 1926.
b. Data for 1971.
c. Abandoned around 1900.
d. Data for 1972.

Land disposal sites are not limited to public ownership. Individual farmers have purchased effluent for crop irrigation on their own land. Sometimes the public agency and the farmer have combined in a system--the municipality selling some effluent and the farmer leasing the city's land and irrigating with the remainder.

Land disposal sites were in existence in 20 states from Massachusetts to California in 1899 [97]. During the first half of the twentieth century, land disposal sites began to predominate in the West as increased land value and increased population led to abandonment of irrigation at many sites in the East. The crude sewage farms of the 1890s have been replaced for the most part (1) by managed farms on which treated wastewater is used for crop production, (2) by landscape irrigation sites, and (3) by groundwater recharge sites.

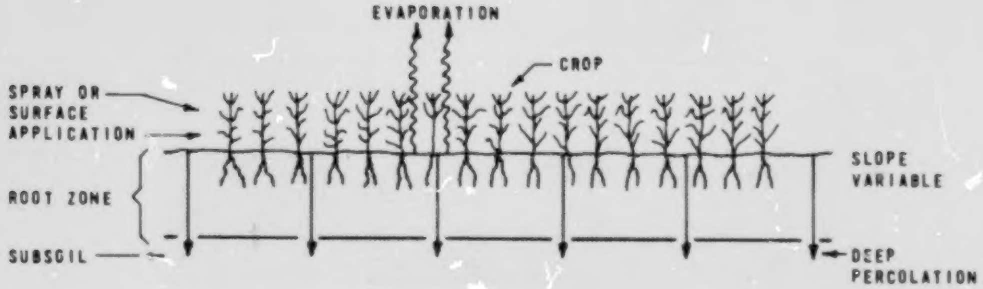
The results of a survey in 1964 indicated that there were 2,192 land disposal systems in the United States, including 1,278 industrial systems and 914 municipal systems (379 surface applications and 535 subsurface septic tank systems) [45]. More recently EPA published a 1972 Municipal Wastewater Facilities Inventory in which 571 surface application systems were identified. The present total number of industrial land application systems was not determined in either this study or the APWA study. The 9 sites visited during this study and the 196 sites contacted during the APWA study represent only a portion of the total land application systems presently in operation.

LAND APPLICATION APPROACHES

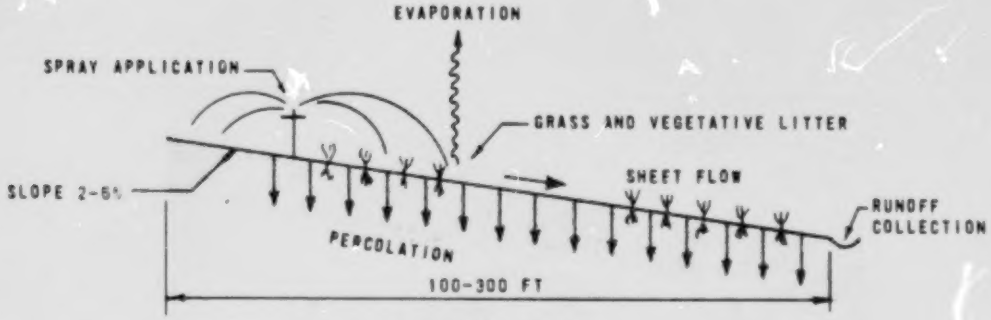
Land application approaches can be classified into three main groups: irrigation, overland flow or spray-runoff, and infiltration-percolation. These approaches are illustrated on Figure 1.

Irrigation

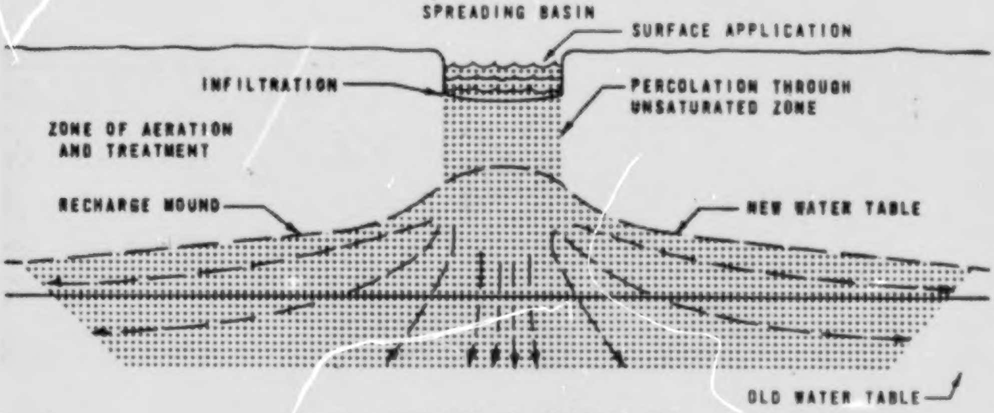
Irrigation is the controlled discharge of effluent, by spraying or surface spreading, onto land to support plant growth. The wastewater is "lost" to plant uptake, to air by evapotranspiration, and to groundwater by percolation. Application rates are measured either in inches per day or week, or in gallons per acre per day. The method of application depends upon the soil, the type of crop, the climate, and the topography. Sloping land is acceptable for irrigation provided that application rates are modified to prevent excessive erosion and runoff.


EVAPORATION
CROP
SPRAY OR SURFACE APPLICATION
ROOT ZONE
SUBSOIL
SLOPE VARIABLE
DEEP PERCOLATION

(a) IRRIGATION


EVAPORATION
SPRAY APPLICATION
GRASS AND VEGETATIVE LITTER
SLOPE 2-6%
SHEET FLOW
RUNOFF COLLECTION
PERCOLATION
100-300 FT

(b) OVERLAND FLOW


SPREADING BASIN
SURFACE APPLICATION
INFILTRATION
PERCOLATION THROUGH UNSATURATED ZONE
ZONE OF AERATION AND TREATMENT
RECHARGE MOUND
NEW WATER TABLE
OLD WATER TABLE

(c) INFILTRATION-PERCOLATION

FIGURE 1
LAND APPLICATION APPROACHES

Renovation of the wastewater occurs generally after passage through the first 2 to 4 feet of soil. Monitoring to determine the extent of renovation is generally not practiced; when it is practiced, however, removals are found to be on the order of 99 percent for BOD and suspended solids. Depending upon the soil type and the crop harvested, removals of nitrogen and phosphorus from the wastewater may also be quite high.

The use of irrigation as a treatment and disposal technique has been developed for municipal wastewater and a variety of industrial wastewaters, including those from the food processing industry, the pulp and paper industry, tanneries, animal feedlots, dairies, and some chemical plants. Crops grown have ranged from vegetables to grasses and cereals.

Overland Flow

Overland flow is the controlled discharge, by spraying or other means, of effluent onto the land with a large portion of the wastewater appearing as runoff. The rate of application is measured in inches per week, and the wastewater travels in a sheet flow down the grade or slope.

Soils suited to overland flow are clays and clay loams with limited drainability. The land for an overland flow treatment site should have a moderate slope--between 2 and 6 percent [24]. The surface should be evenly graded with essentially no mounds or depressions. The smooth grading and ground slope make possible sheet flow of water over the ground without ponding or stagnation. Grass is usually planted to provide a habitat for the biota and to prevent erosion. As the effluent flows down the slope, a portion infiltrates into the soil, a small amount evaporates, and the remainder flows to collection channels. As the effluent flows through the grass, the suspended solids are filtered out and the organic matter is oxidized by the bacteria living in the vegetative litter.

The overland flow treatment process has been developed in this country for treatment of high strength wastewater, such as that from canneries, with resultant reductions in BOD from around 800 mg/L down to as low as 2 mg/L [88]. Reductions of suspended solids and nitrogen are also high although phosphorus reduction is reported to be on the order of 40 to 60 percent. In Australia overland flow or grass filtration has been used for municipal waste treatment for many years, with BOD and suspended solids removals of about 95 percent. Research is presently being conducted on the use of the overland flow treatment system for treatment of raw sewage [124]. No municipal sites where overland flow treatment is being used in the United States were encountered in this study. The design and operation of overland flow systems are discussed in Section VI.

Infiltration-Percolation

This method of treatment is similar to intermittent sand filtration in that application rates are measured in feet per week or gallons per day per square foot. The major portion of the wastewater enters the groundwater although there is some loss to evaporation. The spreading basins are generally dosed on an intermittent basis to maintain high infiltration rates. Soils are usually coarse textured sands, loamy sands, or sandy loams.

This process has been developed for groundwater recharge of municipal effluents, municipal wastewater disposal, and industrial wastewater treatment and disposal. The distinction between treatment and disposal for this process is quite fine. Unquestionably, industrial wastewater applied to the land for the purpose of disposal is also undergoing treatment by infiltration and percolation, whether or not monitoring for detection of renovation is being practiced.

Other Disposal Approaches

There are several other approaches to the disposal of wastewater on land, including subsurface leach fields, injection wells, and evaporation ponds. Such techniques are generally limited in their range of application. Leach fields are prevalent in rural areas and are likely to remain so. The largest known municipal installation employing leach trenches is at North Lake Tahoe, California [1], and is only a temporary design. Details of and criteria for design of leach fields may be found in the *Manual of Septic Tank Practice* [72]. A report by researchers [66] on methods of preventing failure of leach field systems is suggested for further study.

Deep well injection of reclaimed wastewater is being practiced in Orange County, California [138], and has been proposed for Long Island, New York [8, 102]. Because such practices are not considered to be wastewater treatment, they will not be discussed further.

Evaporation ponds also have limited applicability because of the large land requirements and climatic constraints. Although such ponds are designed for disposal, they will act as stabilization ponds and limited treatment by microorganisms will take place. Where crop irrigation or groundwater recharge are not permissible because of high salinity of the wastewater, consideration of evaporation ponds may be in order.

In the United States as opposed to European nations, there are no national regulations for the control of land disposal of effluents. There are federal guidelines for wastewater treatment, but each state must regulate land disposal facilities. The aspect of regulation is discussed in detail in Section IV.

Approach Selection

To make a proper assessment of the type of system or land application approach that is suitable for a given situation requires knowledge of many variables. Some of the factors to be considered are the amount of available land, the need for reclaimed water, the wastewater characteristics and flow rates, the type of soil at available sites, and whether the need is for treatment or disposal. These factors may be classified as regulatory, economic, and technical.

Regulatory Factors – These factors include laws, regulations, and criteria concerning protection of stream quality, groundwater quality, and public health. If the available sites are underlain by aquifers used for potable water supply, public agencies may not allow infiltration-percolation systems. With stream standards becoming increasingly stringent, irrigation with underdrains, overland flow, or infiltration-percolation with recovery may be combined with other forms of wastewater treatment prior to stream discharge.

Economic Factors – The inclusion of land treatment approaches with conventional treatment processes depends, in part, on the economics involved. If wastewater has economic value it can be reclaimed by land application. The most efficient approach in terms of percentage recovery would be infiltration-percolation. If an economic return is important, crops grown using overland flow or irrigation can be sold to recover part of the costs of wastewater treatment. The costs involved in these three land application approaches are evaluated in Section VIII.

Technical Factors – Physical aspects of the available land, such as soil type, underground formations, and ground slope, will influence the approach selection. Other technical factors include wastewater characteristics and flow rates, climate, and whether the flow remains constant throughout the year. For seasonal flows, such as those from canneries, the selection of the overland flow system, like any biological system, must take into account an annual startup period.

Soil classification, an important independent variable, has been graphed against liquid loading rates as the dependent variable. The resultant combinations have been blocked out, as shown on Figure 2, for the typical ranges for each land application approach. These are not intended to be a design guideline but rather a general aid in the process of approach selection.

METHODS OF APPLICATION

There are a number of different ways to apply wastewater to the land. Each site will have its own physical characteristics that will influence the choice of the method of application. The three that are most commonly used are spraying, ridge and furrow, and flooding. Each of these methods is illustrated on Figure 3.

Spraying

In the spraying method, effluent is applied above the ground surface in a way similar to rainfall. The spray is developed by the flow of effluent under pressure through nozzles or sprinkler heads. The pressure is supplied by a pump or a source high enough above the sprinkler heads. By adjusting the pressure and nozzle aperture size, the rate of discharge can be varied to any desired rate.

The elements of a spray system are the pump or source of pressure, a supply main, laterals, risers, and nozzles or sprinkler heads. Since the system operates under pressure, there is a wide variety of ground configurations suitable for this type of disposal. The spray system can be portable or permanent, moving or stationary.

The cost of a spray system is relatively high because of pump and piping costs and pump operating costs. The effluent used in a spray disposal system cannot have solids that are large enough to plug the nozzles. Sprinkling is the most efficient method of irrigation with respect to uniform distribution.

Ridge and Furrow Method

The ridge and furrow method is accomplished by gravity flow only. The effluent flows in the furrows and seeps into the ground. Ground that is suitable for this type of operation must be relatively flat. The ground is groomed into alternating ridges and furrows, the width and depth varying with the amount of effluent to be disposed and the type of soil. The rate of infiltration into the ground will control the

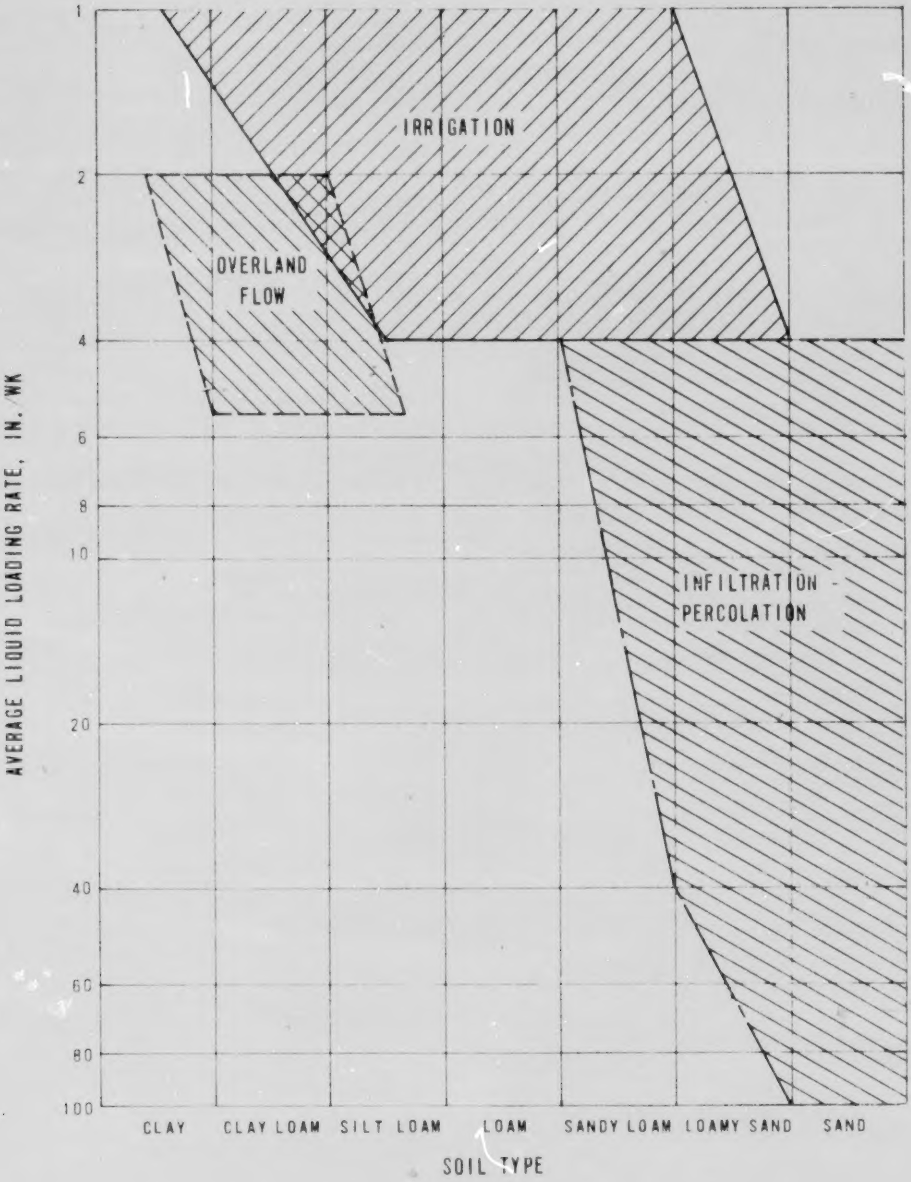
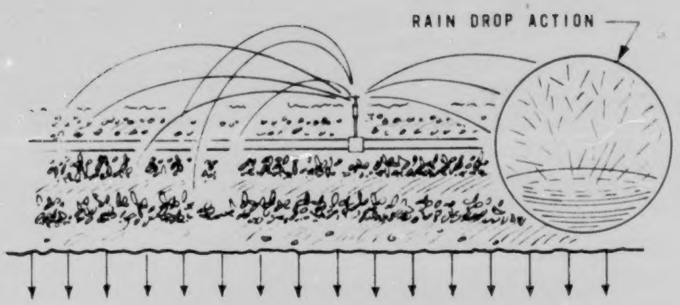
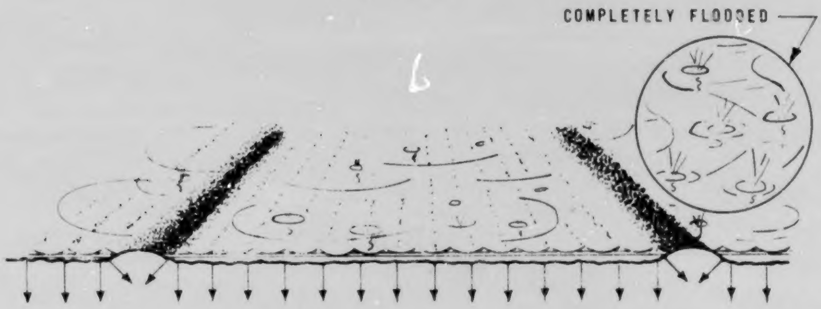


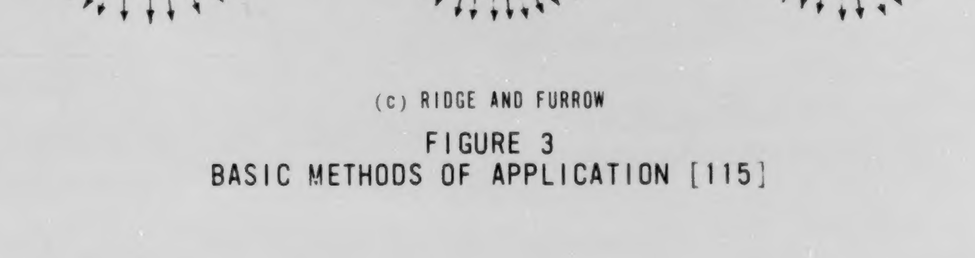
FIGURE 2
SOIL TYPE VERSUS LIQUID LOADING RATES
FOR DIFFERENT LAND APPLICATION APPROACHES


RAIN DROP ACTION

(a) SPRINKLER


COMPLETELY FLOODED

(b) FLOODING



(c) RIDGE AND FURROW

FIGURE 3
BASIC METHODS OF APPLICATION [115]

amount of effluent used. If crops are to be irrigated with effluent, the width of the ridge where the crop is planted will vary with the type of crop. The furrows must be allowed to dry out after application of sewage effluent so that the soil pores do not become clogged.

Flooding

The third type of application is flooding. This type can be accomplished in different ways: border strip, contour check, or spreading basin. Flooding, as the term implies, is the inundation of the land with a certain depth of effluent. The depth is determined by the choice of vegetation and the type of soil. The land has to be level or nearly level so that a uniform depth can be maintained. The land does need "drying out" so that soil clogging does not occur. The type of crop grown has to be able to withstand the periodic flooding. The three methods are illustrated on Figure 4.

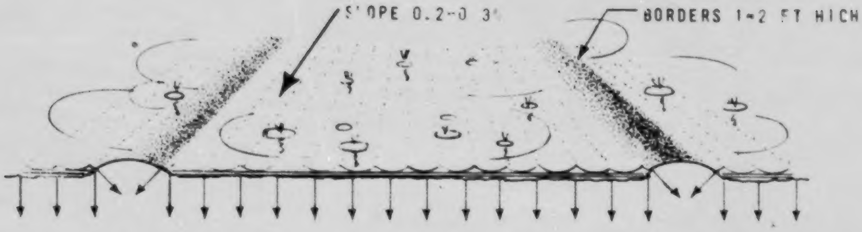
The border strip method consists of sloped (0.2 to 0.3 percent) strips of land 600 to 1,000 feet long divided by borders or dikes every 20 to 60 feet [142]. The major difference between this method and the spreading basins is that this method uses smaller segments of a field and the ground is sloped.

Contour check is the creation of dikes or levees along the contour of a hill or slope. The dikes contain the effluent so it does not run down the slope. The dikes are generally placed at contour intervals of 0.2 to 0.3 feet.

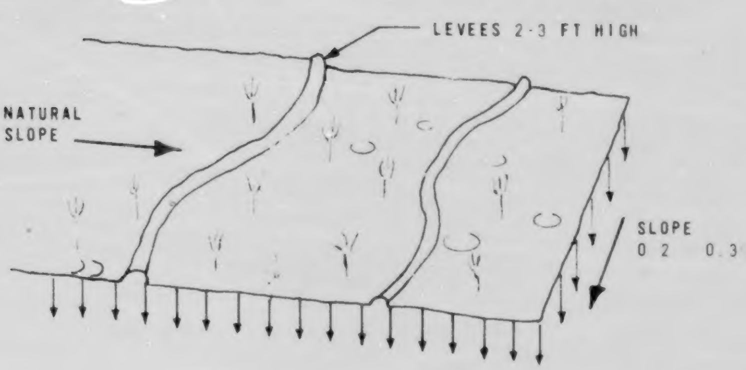
Spreading basins are shallow ponds which are periodically flooded with effluent. The basins hold the effluent until it percolates into the ground, is used by crops, or evaporates into the air. Spreading basins are generally used for rapid infiltration.

WASTEWATER CHARACTERISTICS

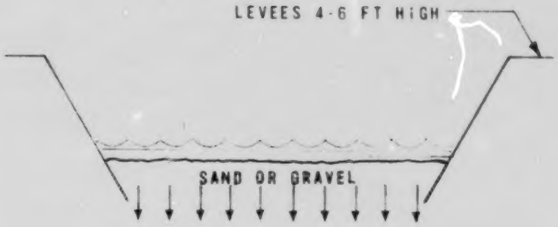
The characteristics of wastewater may be classified as physical, chemical, and biological. Because industrial wastewater characteristics are so diverse, even among the food processing and pulp and paper industries, they are discussed in Section VI. Municipal wastewater characteristics are listed in Table 2 for (1) untreated wastewater, (2) a typical secondary effluent, and (3) effluents that have been applied to the land. The degree of pretreatment normally given by secondary treatment processes can be seen by comparing columns 1 and 2. A discussion of the effects of pretreatment by conventional wastewater treatment processes on characteristics is presented at the end of this section.


SLOPE 0.2-0.3%
BORDERS 1-2 FT HIGH

(a) BORDER STRIP


LEVEES 2-3 FT HIGH
NATURAL SLOPE
SLOPE 0.2 0.3

(b) CONTOUR CHECK


LEVEES 4-6 FT HIGH
SAND OR GRAVEL

(c) SPREADING BASIN

FIGURE 4
TYPES OF FLOOD IRRIGATION

Table 2. Municipal Wastewater Characteristics

	mg/L (except as noted)		
Constituent	Untreated sewage (1)	Typical secondary treatment effluent (2)	Actual quality applied to land (3)
Physical			
Total solids	700	425	760-1,200
Total suspended solids	200	25	10-100
Chemical			
Total dissolved solids	500	400	750-1,100
pH, units	7.0±0.5	7.0±0.5	6.8-8.1
BOD	200	25	10-42
COD	500	70	30-80
Total nitrogen	40	20	10-60
Nitrate-nitrogen	0	--	0-10
Ammonia-nitrogen	25	--	1-40
Total phosphorus	10	10	7.9-25
Chlorides	50	45	40-200
Sulfate	--	--	107-383
Alkalinity ($CaCO_3$)	100	--	200-700
Boron	--	1.0	0-1.0
Sodium	--	50	190-250
Potassium	--	14	10-40
Calcium	--	24	20-120
Magnesium	--	17	10-50
Sodium adsorption ratio	--	2.7	4.5-7.9
Biological			
Coliform organisms, MPN/100 ml	10^6	--	$2.2\text{-}10^6$

Sources:

Column 1 – Medium strength [80].
Column 2 – [5].
Column 3 – Range of values obtained from site visits.

Physical Characteristics

The most important physical characteristic of wastewater is its total solids content. The solids include floating, suspended, colloidal, and dissolved matter.

The solids are important because they have a tendency to clog the soil pores and coat the land surface. Other physical characteristics are temperature, color, and odor. Temperature is not a great problem because municipal wastewater effluent has a fairly even temperature, 50 deg F to 70 deg F, which is not harmful to soil or vegetation. It is beneficial in that in winter, it has a thawing effect on frozen ground and may keep soil bacteria alive. Effluent has been used to spray on crops in freezing weather to form an insulating ice coating which protects the crop from cold air [90].

Color of effluent has little effect on the application to the crops, but it can be used as an indicator of the composition of the wastewater. Fresh sewage is usually grey; septic or stale sewage is black. The presence of industrial wastes can give the sewage color from chemicals in the waste.

Odors in wastewater are caused by the anaerobic decomposition of organic matter. Although hydrogen sulfide is the most important gas formed from the standpoint of odors, other volatile compounds such as indol, skatol, and mercaptons also cause noxious odors. These odors are then released to the atmosphere by spraying or aerating.

Chemical Characteristics

The chemical properties of wastewater can be divided into three categories: organic matter, inorganic matter, and gases.

The organic matter in wastewater is in the dissolved form as well as settleable solid form, and it is principally composed of proteins (40 to 60 percent), carbohydrates (25 to 50 percent), and fats and oils (10 percent). Other organic compounds, such as phenols, surfactants, and agricultural pesticides, are generally present in small quantities. Only when the trace organics reach higher concentrations do they become a problem. Ordinarily these substances are in such a small quantity that they have no short term effect on the soil or vegetation; however, their effect on groundwater quality is a point of concern. Long term effects of trace organics have not been adequately determined.

Many of the inorganic compounds provide nutrients for the vegetation, but they also can be toxic to plants at certain concentrations. Examples include boron, lead, nickel, and zinc. The major plant nutrients present in wastewater are nitrogen, phosphorus, and potassium. The aggregate of dissolved compounds is the TDS (total dissolved solids). The TDS content, often measured as electrical conductivity, is generally more important than the concentration of a specific ion such as chloride. TDS values above 750 mg/L for irrigation waters will require leaching either by adding excess irrigation water or from rainfall.

The relationship between the principal cations in wastewater--calcium, magnesium, sodium, and potassium--is of importance. When the ratio of sodium to the other cations, especially calcium and magnesium, becomes too high, the sodium tends to replace the calcium and magesium ions on clay particles. The predominance of sodium ions on clay particles has the effect of dispersing the soil particles and decreasing the soil permeability. To determine the sodium hazard, the SAR (sodium adsorption ratio) has been developed by the U.S. Department of Agriculture Salinity Laboratory and is described in detail in Agricultural Handbook No. 60 [130]. It is defined as follows:

$$\mathrm{SAR} = \mathrm{Na}/[1/2\ (\mathrm{Ca} + \mathrm{Mg})]^{1/2}$$

where Na, Ca, and Mg are concentrations of the respective ions in milliequivalents per liter of water.

Gases in wastewater, other than those mentioned in regard to odors, are relatively unimportant in land application. Dissolved oxygen is usually depleted soon after wastewater is applied to the land. Atmospheric oxygen is relied upon for maintenance of aerobic soil conditions.

Biological Characteristics

Wastewater is teeming with microorganisms that are constantly changing its characteristics. The predominant microorganisms are bacteria.

Wastewater may contain pathogenic organisms which cause diseases, such as salmonella gastroenteritis, typhoid and paratyphoid fevers, bacillary and ameobic dysentery, cholera, and infectious hepatitis [31]. Pretreatment is required to remove the bulk of these microorganisms from the wastewater. The presence of enteric pathogens is often ascertained by testing for coliforms. *E. coli* (*Escherichia coli*) are used as indicator organisms because they are more numerous and more easily tested for than pathogenic organisms. Tests have also been developed to distinguish between total coliforms, fecal coliforms, and fecal streptococci. These tests are important because many common soil bacteria are measured in a total coliform count. It is therefore important that those bacteria that originate in the digestive tract of man be isolated to measure the degree of wastewater renovation in the soil system.

Effects of Pretreatment on Wastewater Characteristics

Conventional wastewater treatment begins with preliminary operations such as screening and sedimentation. Effluent from these operations is referred to as primary effluent. This primary effluent may be further treated by biological oxidation or by physical-chemical processes. Effluent from the more widespread biological processes, such as activated sludge, trickling filters, or oxidation ponds, is referred to as secondary effluent. Constituents removed by the various operations and processes in conventional treatment will be noted in the following discussion.

Primary Treatment – Coarse screens, present in nearly every treatment plant, remove large floating objects and rags. Fine screens are generally not used anymore in sewage treatment because the smaller solids are removed by sedimentation and biological oxidation.

Sedimentation removes much (50 to 65 percent) of the suspended solid matter in the wastewater. Grit and gross settleable solids are often removed in grit chambers prior to primary sedimentation. BOD is reduced by primary sedimentation approximately 25 to 40 percent [80], and some organic nitrogen, phosphorus, and heavy metals are also settled out.

Sedimentation will remove most of the Ascaris eggs, but beef tapeworm eggs, hookworm, amoeba cysts, Salmonella, and viruses will not be completely removed [111]. Most of the dissolved and colloidal matter present in wastewater will not be removed in primary treatment.

Secondary Treatment – Biological oxidation results in the removal of colloidal and dissolved organics to a large extent. Additionally, some nitrogen and phosphorus are incorporated into bacterial cells and removed by secondary sedimentation. Most dissolved inorganics are not affected by secondary treatment. Secondary treatment provides an additional removal of bacteria and viruses by flocculation and secondary sedimentation.

Disinfection - Disinfection, the selective destruction of disease-causing organisms, may be accomplished using heat, ozone, bromine, iodine, or, most commonly, chlorine. Adequate disinfection requires complete and rapid mixing and minimum contact time. The presence of suspended solids hinders the process of disinfection; therefore, secondary effluent is more readily disinfected than primary effluent. The number of coliform organisms can be reduced by disinfection techiques from 10^6 organisms per 100 ml to less than 2.2 organisms per 100 ml.

WASTEWATER RENOVATION MECHANISMS

The soil matrix represents a treatment zone where many complex physical, chemical, and biological processes and interactions contribute to the renovation of wastewater applied to the land. The major renovation mechanisms include uptake by plant roots, precipitation, adsorption, oxidation, ion exchange, and filtration. Although the theory of each will not be discussed in detail, the mechanisms active in the removal of important constituents from the wastewater will be identified. The constituents to be considered are suspended solids, organic matter, nitrogen, phosphorus, heavy metals, boron, other dissolved solids, bacteria, and viruses.

Suspended Solids

Suspended solids in wastewater may be organic (volatile) or inorganic (fixed). The destruction of volatile solids is discussed under "Organic Matter." The fixed or inorganic suspended solids will become incorporated into the soil through filtration and will not be discussed further.

Organic Matter

The biodegradable organics measured by the BOD can be almost totally removed by the soil matrix. The mechanism of filtration separates the suspended organics from the wastewater as it infiltrates the soil, and bacterial oxidation destroys the trapped particles. This overall removal generally occurs in the upper 5 to 6 inches of soil [65] and the major filtration often occurs in the top few centimeters [126]. Dissolved organics, both biodegradable and resistant, are removed initially by adsorption on clay and humus material, and subsequently the degradable organics are oxidized by microorganisms. The degradation process occurs slowly for resistant compounds, such as pesticides, cellulose, detergents, and phenols [63]. However, the presence of high concentrations of phenols and similar organics can be toxic to microorganisms.

Nitrogen

Nitrogen contained in wastewater applied to the land may be in any of four forms: organic, ammonium, nitrate, and nitrite. Nitrite nitrogen is easily oxidized to nitrate in the presence of oxygen so that concentrations above 1.0 mg/L for nitrite are rare. Nitrate nitrogen may be applied to the land when effluents are nitrified. The process of nitrification is the overall biological oxidation of ammonium to nitrite followed by oxidation of nitrite to nitrate. Nitrification, mineralization, and denitrification are biological processes that can occur in soil as shown on Figure 5.

Generally, organic and ammonium nitrogen are the principal forms applied to land. Organic nitrogen, being suspended instead of dissolved, is filtered out in the soil matrix and mineralized (decomposed) into ammonium nitrogen. Ammonium exists in equilibrium with ammonia gas and, at a pH between 7.5 and 8.0, 10 percent of the nitrogen will be in the gaseous ammonia form [56]. Volatilization of significant quantities of ammonia requires not only a high pH but also considerable air-water contact [121]. Therefore, the mechanism is not expected to provide significant nitrogen removal in land application systems.

In the soil the ammonium ion participates in ion exchange and competes with other actions for exchange sites on organic and mineral fractions of the soil. However, in the presence of clay minerals and certain organic soil fractions, ammonium ions are preferentially adsorbed. These adsorbed ions can be held tightly and may be resistant to leaching. While in the adsorbed phase, ammonium is available to some plants for direct uptake and to microorganisms for incorporation into cell tissue or for conversion to nitrate under aerobic conditions. Only ammonium adsorbed in a zone that remains anaerobic is stable [56].

Nitrate nitrogen is not retained in soil by adsorption or ion exchange, but instead leaches readily with applied water [109]. The mechanisms for nitrate removal from wastewater in soil are plant uptake and denitrification. Denitrification can be a chemical reaction between organic matter and nitrates, or a biological process in which bacteria, under anaerobic conditions in the presence of organic matter, reduce nitrates to nitrogen gas. The conditions necessary for significant chemical denitrification do not normally occur in soil systems used for wastewater application. Biological denitrification can be promoted by system management techniques discussed later in the report.

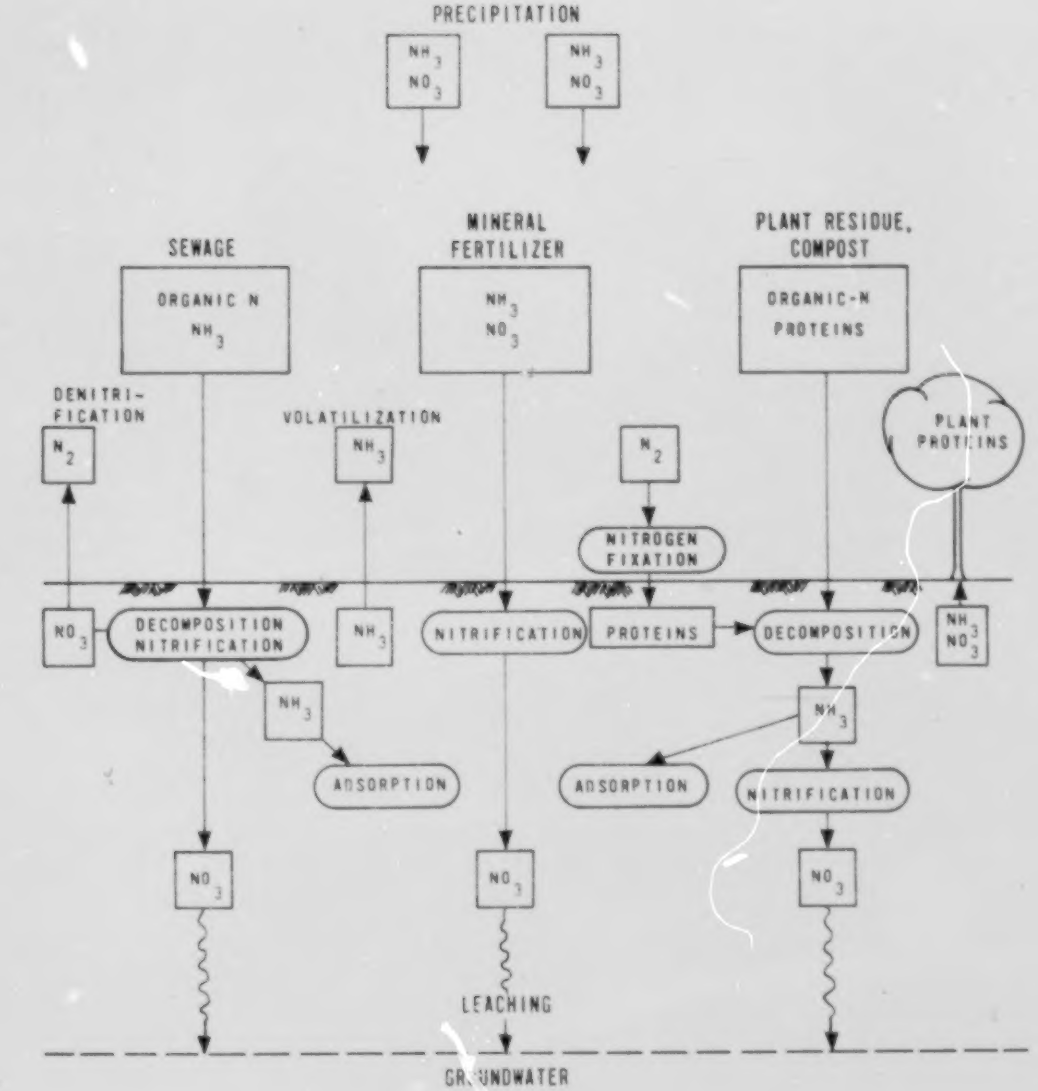

PRECIPITATION
NH_3 NO_3
NH_3 NO_3
SEWAGE
ORGANIC N
NH_3
MINERAL FERTILIZER
NH_3 NO_3
PLANT RESIDUE, COMPOST
ORGANIC-N
PROTEINS
DENITRI-FICATION
N_2
VOLATILIZATION
NH_3
N_2
NITROGEN FIXATION
PLANT PROTEINS
NO_3
DECOMPOSITION NITRIFICATION
NH_3
NITRIFICATION
PROTEINS
DECOMPOSITION
NH_3 NO_3
NH_3
ADSORPTION
NH_3
ADSORPTION
NITRIFICATION
NO_3
NO_3
NO_3
LEACHING
GROUNDWATER

FIGURE 5
NITROGEN CYCLE IN SOIL [109]

Phosphorus

Phosphorus occurs mostly in the form of orthophosphates which are removed from solution primarily by the fixation process described previously for ammonium, and by precipitation as insoluble phosphates [101]. It has been reported that the amount of phosphorus removal by fixation is less at pH values between 6 and 7 than for either higher or lower pH values [101]. Phosphorus can also be removed by plant uptake and by incorporation into biological solids. These two mechanisms are important in overland flow systems.

Heavy Metals

Retention of heavy metals in the soil matrix is by adsorption and ion exchange. Removal of metals from solution by precipitation occurs to some extent, especially in the presence of sulfides. Heavy metals are also taken up by plant and microbial cell synthesis in small amounts. Under low pH conditions, metals can be leached out of soil systems. Recent research indicates that up to 300 mg/L of chromium and zinc can be removed by ion exchange in the soil [137].

Boron

Boron is an essential plant micronutrient but is toxic to most plants at 1 to 2 mg/L [67]. Thus, very small quantities are removed from solution by plant intake. Boron can be removed in the soil by adsorption and fixation in the presence of iron and aluminum oxides [100], but only to a limited extent [133]. Consequently, it should be considered that boron not removed by plant uptake will leach through soil systems.

Other Dissolved Solids

Potassium, calcium, magnesium, sodium, iron, manganese, and chlorides are taken up by plants, undergo ion exchange, and leach out of soils relatively easily. Potassium is taken up by crops to the largest extent, while chlorides, bicarbonate, and sulfate pass essentially unaffected through the soil. Depending upon the initial chemical composition of the soil matrix, the total dissolved solids of the renovated water may increase, decrease, or remain the same as the applied wastewater. For instance, infiltration-percolation through saline soil will result in an increase in TDS in the percolate until steady state conditions are reached. In infiltration-percolation systems that are well established, there should be little change in TDS in the renovated water as compared to the influent. For irrigation, however, with considerable evaporation of applied water taking place, an increase in TDS in the soil water is usually seen.

Bacteria and Viruses

Bacteria are removed by a combination of straining, die-off, sedimentation, entrapment, and adsorption [53]. Enteric pathogens may survive in soil for up to 2 months and retain their virulence during the survival period [65]. In spraying wastewater, some bacteria are intercepted by vegetation where dessication, die-off, and predators eliminate them. Predators such as insects and worms are also present in the soil system. Viruses are removed as effectively as bacteria, principally by adsorption [28, 33, 53]. Survival times of viruses adsorbed in the soil matrix have not been explored.

SECTION IV

IRRIGATION WITH MUNICIPAL WASTEWATER

Irrigation is the most common form of land application in the United States with some 367 communities employing the practice as of 1964 [45]. Of the 571 land application facilities inventoried by EPA in 1972, 315 were identified as practicing irrigation. Although it is widespread, especially in the southwest, there are many complex factors involved in cropland, forest, or landscape irrigation. The major factors have been classified as those relating to (1) system design, (2) management and operation, (3) environmental effects, and (4) public health considerations. In an attempt to put these factors into perspective, an analysis is included on reasons for irrigation abandonment. Each of these factors will be discussed in the remainder of this section.

SYSTEM DESIGN

Items that must be considered in an irrigation system design include the factors important in the selection of the site, the various techniques of applying the water to the land, and the design criteria.

Factors in Site Selection

Factors important in site selection include climate, soil characteristics and depth, topography, and hydrologic and geologic conditions. A tabulation of factors and generalized criteria for an irrigation site is listed in Table 3.

Climate – The macroclimate at a site cannot be changed by present technology so the different factors of the climate must be studied with respect to their influence upon the proposed system. Factors such as temperature range, annual precipitation, humidity, and wind velocity have a direct effect on the amount of water that can be disposed of at a certain location. These factors also have an effect on the type of crop that can be grown successfully in that area.

8

Table 3. Site Selection Factors and Criteria for Effluent Irrigation

Factor	Criterion
Soil type	Loamy soils preferable but most soils from sands to clays are acceptable.
Soil drainability	Well drained soil is preferable, consult experienced agricultural advisors.
Soil depth	Uniformly 5 to 6 ft or more throughout sites is preferred.
Depth to groundwater	Minimum of 5 ft is preferred. Drainage to obtain this minimum may be required.
Groundwater control	May be necessary to ensure renovation if water table is less than 10 ft from surface.
Groundwater movement	Velocity and direction must be determined.
Slopes	Up to 15 percent are acceptable with or without terracing.
Underground formations	Should be mapped and analyzed with respect to interference with groundwater or percolating water movement.
Isolation	Moderate isolation from public preferable, degree dependent on wastewater characteristics, method of application, and crop.
Distance from source of wastewater	A matter of economics.

The consumptive use by plants is in direct relation to the climate of the area. Consumptive use or evapotranspiration is the total water used in transpiration, stored in plant tissue, and evaporated from adjacent soil [11]. The consumptive use varies with the type of crop, humidity, air temperature, length of growing season, and wind velocity. The amount of water lost by evapotranspiration can be estimated from the pan evaporation data supplied by the U.S. Weather Bureau in the vicinity of the site. The amount of evapotranspiration is equal to a crop factor times the amount of pan evaporation. The crop factor varies with the type of crop and the location [115]. Presently available crop factors have been derived for use under natural moisture conditions or prevalent irrigation practices and may not be applicable to wastewater irrigation at high rates. Other methods of estimating evapotranspiration may be found in references [11, 65, 24].

The length of the growing season affects the amount of water used by the crop. The length of the growing season for perennial crops is generally the period beginning when the maximum temperature stays well above the freezing point for an extended period of days, and continues throughout the season despite later freezes [11]. This period is related to latitude and hours of sunlight as well as the net flow of energy or radiation into and out of the soil. A limited growing season will require long periods of storage or alternate methods of winter disposal.

Soil Characteristics – Important soil characteristics include drainability and balance of certain chemical constituents. Drainability depends primarily on the mechanical properties of texture and structure. These properties are largely influenced by the relative percentage of the three mechanical classes of soil--sand, silt, and clay. Coarse sand particles range in size from 2.0 mm to 0.25 mm; fine sand particles, from 0.25 mm to 0.05 mm; silt particles, from 0.05 mm to 0.005 mm; and particles smaller than 0.005 mm are clay. The relationship among these classes and the nomenclature of soils is shown on Figure 6.

Clay soils do not drain well. Soils with a relatively high content of clay are fine textured and often described as heavy. They retain large percentages of water for long periods of time. As a result, crop management is difficult but not impossible. These soils expand or swell with moisture increases, and at such times the soil structure is susceptible to being destroyed by compaction or cultivation. When clay soils dry there is often considerable shrinkage and the ground becomes cracked and very hard.

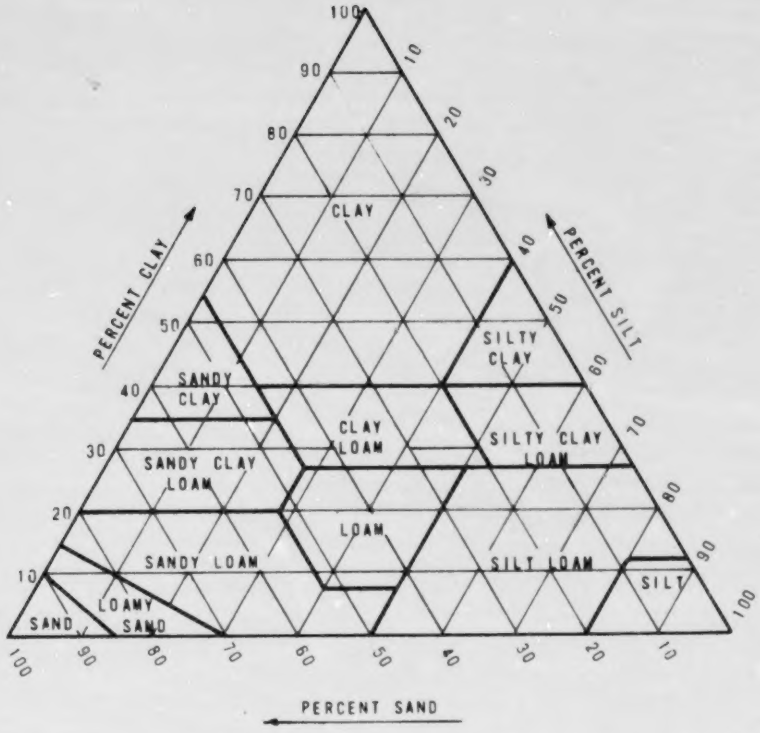

100
90
80
70
60
50
40
30
20
10
PERCENT CLAY
PERCENT SILT
PERCENT SAND
CLAY
SILTY CLAY
SANDY CLAY
CLAY LOAM
SILTY CLAY LOAM
SANDY CLAY LOAM
LOAM
SANDY LOAM
SILT LOAM
SILT
LOAMY SAND
SAND

FIGURE 6
PROPORTIONS OF SAND, SILT AND CLAY
FOR DIFFERENT SOIL TEXTURES [115]

On the other hand, sandy soils do not retain moisture very long, which is important for crops that cannot withstand prolonged submergence or saturated root zones. An example of plants harmed by too much water occurred at Detroit Lakes, Minnesota, where a heavy effluent application (6 in./day) resulted in the death of a number of trees [57]. Soils are considered to be well drained if the infiltration rate (entrance velocity of water into soil) is 2 in./day or more as measured in full-scale tests. The drainability should be determined for a large area (as will be discussed under loading rates), not for a localized test pit.

Drainage also depends upon the absence of lateral and subsurface constraints to the flow of water. An example of lateral constraint would be a sandy soil in a narrow valley with impermeable clay or rock on all sides. The lateral transmissibility and percolation rate must be equal to or higher than the infiltration rate to avoid ponding and waterlogging of soil.

The balance of chemical constituents in the soil is important to plant growth and wastewater renovation. The mechanisms of retention of certain constituents by the soil have been discussed in Section III under "Wastewater Renovation Mechanisms." Factors such as salinity, alkalinity, and nutrient level of the soil should be determined prior to planting and should be monitored during irrigation to determine the rate and extent of any buildup. The Soil Conservation Service has produced extensive soil maps delineating soil physical characteristics to depths of 5 feet for most parts of the United States.

Some of the indicators of adverse soil conditions are pH, conductivity, and SAR (sodium adsorption ratio, defined in Section III). Most crops grow best in a soil with a neutral or slightly acid pH. Both highly acid and alkali conditions can produce sterile soil. Additions of calcium sulfate (gypsum) will aid alkali soils, and calcium hydroxide (lime) will aid acid soils. The salinity or TDS of the soil is commonly measured as electrical conductivity. In arid regions where annual evaporation is substantially in excess of annual precipitation, salts will accumulate in nearly all soils unless leaching is done. According to the University of California Committee on Irrigation Water Quality Standards, there is a definite hazard to permeability from using water having an SAR of 8 or more on certain soils [17].

The adverse factors of high salinity, pH, and SAR may occur in the same soil producing a saline-alkali soil. Saline soils are those with conductivities of saturation extracts greater than 4,000 micromhos/cm. It has been found that the conductivity of the saturation extract of a soil, in the absence of salt accumulation from groundwater, usually ranges from 2 to 10 times as high as the conductivity of the applied irrigation water [11].

Soil Depth — Adequate soil depth is important for root development, for retention of wastewater components on soil particles, and for bacterial action. Roots from plants can extract water from depths ranging from 1 to 9 feet or more. Retention of wastewater components such as phosphorus, heavy metals, and viruses is a function of residence time of wastewater in the soil and the degree of contact between soil colloids and the wastewater components.

In the soil there are different layers with varying levels of activity. The activity diminishes when the groundwater table is reached and the soil is saturated. The different zones are the surface, root zone, and subsoil.

The surface of the ground is where the major filtering action of the soil occurs. During infiltration the water passes between the soil particles, and any solids in the water larger than the soil pores will be filtered out. Since the soil surface is in contact with the air, a great amount of aerobic bacterial activity can occur. Large accumulations of solids will form a coating or slime surface on the soil and block air and water from passing through. A drying period will help eliminate the coating. Odors caused by anaerobic conditions can be present if the slime coating is not eliminated.

The root area is an area of great activity. Since it is near the surface, aerobic bacteria are working to break down the organic substances. The roots are absorbing nutrients and water. The depth of this activity depends on the type of plant and type of soil. Plants such as alfalfa can have roots 9 feet or more into the ground. Generally, this activity is limited to a depth of about 4 to 5 feet.

The subsoil level is the area between the root zone and the groundwater table. This is a zone of lessening aerobic bacteria activity and is highly variable in depth. The water content of the soil is generally high, almost to the saturated state.

Groundwater — The groundwater table is the level where free water is present in the soil. The soil is saturated, and bacteria and dissolved solids can travel freely in the water between soil particles.

Before a site is selected a great deal about the groundwater should be known, including depth, variation of depth throughout the site, seasonal variation of depth, direction of groundwater flow, and groundwater quality. If the groundwater is far below the surface (> 100 feet), it may take many months for the applied water to reach it. The applied water may, however, move laterally and join some adjacent aquifer or emerge as seepage water. As several levels of groundwater may underlie the site, the quality and movement potential of each must be determined unless it is shown that the lower zones are separated by impervious strata.

To ensure an aerobic root zone, it is preferred that the groundwater level be maintained at least 5 feet below the ground surface [106]. The groundwater table can be controlled in two ways: by installation of an underdrainage system, or by pumping from wells near the site. Both of these methods have been used successfully in practice. Underdrains have been used in Europe since the 1800s [96, 97].

Topography - The topography of the site for cropland irrigation must be such that farm equipment can be used for planting and harvesting. If the existing topography is not suitable, the site can be engineered to make it acceptable for the type of application of wastewater and the type of crop. The ground slope, if too steep or too uneven, can be leveled or graded to acceptable limits. Leveling and terracing are the two common methods of changing the slope of the site.

The different application methods require different ground slopes. Spray irrigation has been applied to slopes up to 30 percent [110]. Ridge and furrow irrigation has been accomplished by terracing hillsides [10]. Flooding requires slopes of less than 1 percent.

Native vegetation on the site must be either removed or incorporated into the design and operation of the system. The existing vegetation may aid in the determination of the types of crops that will be best suited for the site.

Hydrologic and Geologic Conditions - Groundwater is the most important hydrologic and geologic factor and has been discussed separately. Other important factors are rainfall and resultant storm runoff, the nature of the hydrologic basin, and the nature of underlying rock formations. Rainfall will reduce the capacity of the soil to absorb wastewater and may require storage or lowering of wastewater loading rates. Storm runoff must be routed around the site instead of being allowed to cross the site. If the underlying rock is fractured or crevassed like limestone, percolating wastewater may short-circuit to the groundwater, thus receiving less treatment.

Method of Application

The three methods of application--spraying, ridge and furrow, and flooding--were described previously. Design considerations relating to each will be described here.

No irrigation system is completely efficient. Irrigation efficiency is the percentage of irrigation water that is made available for consumptive use by crops. Efficiency is a function of application method and rate, soil type, land preparation, and management skill. Generally, the water not consumptively used by plants (and lost to evapotranspiration) is lost to deep percolation or surface runoff. Surface runoff, although a function of management, may range from 5 percent for porous, open soil to 25 percent for heavy clay. Deep percolation loss is more a function of soil type and method of application. For light, porous soils, deep percolation losses may approach 35 percent, while for heavy clay they may be as low as 10 percent. Surface irrigation techniques are generally more susceptible to losses to deep percolation than spray irrigation techniques.

Spraying – Sprinkler nozzles range in size from 1/16 inch to 2 inches in diameter. The normal range in wastewater irrigation is from 1/4 inch to 1 inch. Nozzles are generally mounted on risers which should be tall enough for the jet from the sprinkler nozzle to clear the mature plant foliage. Sprinklers may be low pressure (5 to 30 psi), intermediate pressure (30 to 60 psi), or high pressure (above 60 psi) [89]. Low-pressure and intermediate pressure applications may be used on all field crops and soil types with rates as low as 0.1 in./hr. High-pressure applications exceeding 1/3 in./hr may result in compaction of fine textured soil, and may result in injury to crops.

The wind and rate of infiltration of the soil are two major factors in the design of a sprinkler system. The prevailing wind will blow the spray pattern causing uneven distribution and even dry areas under adverse conditions. A certain amount of spray overlap is recommended. The lateral spacing should be 65 percent of the spray diameter for no wind and 50 percent for winds with velocities from 5 to 10 mph. High pressure sprays suffer uneven distribution when wind velocities exceed 4 mph [89].

When wastewater is being sprayed a buffer zone around the site is recommended. A recently designed system has a buffer zone of 200 feet around the site [34], while in Europe requirements for buffer zones have been for as much as 1/4 mile [111]. Studies have shown that downwind travel of spray increased 85 feet for every 2.25-mph increase in wind velocity [111]. Spraying should cease during high winds.

Application rates should not exceed the ability of the soil to absorb the water applied. If the infiltration rate of the soil is exceeded, ponding will occur which could damage a crop and possibly lead to odor or mosquito problems. The size of nozzle, water pressure, and nozzle spacing will be determined by the application rate. Data on sprinkler sizing and spacing may be found in references [89, 118].

A new form of spray irrigation that is currently under study is trickle irrigation. The holes in the distribution pipe are very small (0.020 inch), and the line pressure is very low (0.5 psi). With holes so small, the wastewater could not contain suspended solids to any great extent or clogging would occur. More study is needed before trickle irrigation can be used for wastewater disposal.

Ridge and Furrow – Ridge and furrow irrigation of crops may be used where spray irrigation is not preferred because of high winds, tight soil, or higher cost. This form of irrigation needs extensive amounts of land preparation before the liquid is applied. The land must be relatively flat and the ridges and furrows must be formed to spread the water. Uniform distribution of the water is fairly difficult to maintain with this type of irrigation. Row crops, such as corn and tomatoes, are grown on the ridges and wastewater, at a depth of 2 to 6 inches, travels down the furrows.

Typical ridges are 8 to 10 inches high on 36- to 48-inch centers, with furrows 10 to 16 inches wide and 6 to 10 inches deep [113]. Furrows may be 150 to 500 feet long.

Flooding – Flooding is another type of irrigation that has been used for crop irrigation, as indicated in Section III. The site must have a slight slope (0.2 to 0.3 percent) or be terraced so that uniform distribution can occur. On unleveled sloping ground, the process of contour check may be used. Rice, orchards, and some field grains are irrigated in this manner.

Alfalfa and grasses used for hay are generally irrigated by the border strip method of irrigation. Applications of 2 to 4 in./day are typical with resting periods of 5 to 20 days.

Design Criteria

Criteria for design of irrigation systems include (1) wastewater quality and pretreatment; (2) liquid, nitrogen, and organic loading rates; (3) land requirements; (4) drying period; (5) crop requirements; (6) distribution system design; and (7) flexibility for seasonal or climatic changes.

Wastewater Quality and Pretreatment – Pretreatment of wastewater to be used for irrigation is needed (1) to protect the health and hygiene of persons contacting the wastewater or the crops, (2) to reduce the prevalence of odors, and (3) to improve operational efficiency and reliability.

The aspect of health and hygiene must be considered when wastewater is used for irrigation of crops. Wastewater applied to forage and fiber crops is not required to be disinfected to a high level in most states. So long as such crops are irrigated in fields that are posted or fenced and by surface techniques, no hazard should arise. This aspect of irrigation will be treated in detail under "Public Health Considerations."

Since wastewater can become very odorous if it becomes anaerobic, measures must be taken to prevent this from occurring. When the wastewater is an effluent from a secondary treatment plant, the odor problem is not likely to occur. The treatment processes remove most of the organic matter that might produce odors in decomposition. If primary effluent is the irrigation source, then precautions must be taken so that the soil does not become clogged or waterlogged and as a result become anaerobic. The best method of prevention of anaerobic conditions is to allow the soil to dry between applications. The drying period allows air to circulate down into the soil and create an aerobic environment. Another aid is to till or cultivate the soil, without harming the crops, to help the air circulation and break up any sealing coatings.

If spray irrigation is used, the solids content must be such that the sprinkler heads do not clog. This means some sedimentation or screening of the wastewater is desirable before it is pumped into the system. The diameter of the nozzle should be more than three times the diameter of the solids allowed in the irrigation water to prevent clogging.

Liquid Loading Rates - The loading rate of wastewater is affected by conditions of the soil, climate, and crop. The liquid loading rate must be adjusted to the crop use and the percolation rate of the soil so that ponding does not occur. Loading rates and crops for various selected sites are listed in Table 4. Many municipalities grow forage crops because of the health regulations imposed on wastewater irrigation of edible crops and because the forage crops are generally easier to grow and market. The existing loading rates have been classified as high, moderate, or light so that a general correlation with soil type can be made.

It should be noted that the higher loading rates of 7 in./wk and more put those sites into the classification of infiltration-percolation as they result in annual loadings of more than 30 feet. A hydraulic application of 2 to 8 ft/yr has been considered the normal range for the classification of systems under the irrigation approach [124]. For this report irrigation will encompass hydraulic loading rates up to 4 in./wk on a seasonal basis with an annual load of 8 ft/yr. For the systems included in Table 4, the liquid loading rate is seasonal, not continuous for the whole year unless otherwise noted.

The determination of the liquid loading rate can be made from experience with closely similar conditions, consultation with agricultural experts, or from pilot work. It should not be made solely on the basis of percolation tests. Percolation tests are negative tests. Characteristically they indicate infiltration rates (for a very specific point on a site) that are excessive and do not reflect the infiltration rates that can be expected under managed, full-scale conditions with a growing crop.

The hydraulic loading capacity will vary with each site; however, a few examples may be informative. At Lubbock, Texas, the limit of hydraulic loading for the clay loam soil without underdrains appears to be 2 in./wk. When this loading was approached in 1938, 1947, and 1953, additional land was purchased to reduce the loading rate which is now about 1.3 in./wk [42]. The hillside sprinkler system at South Lake Tahoe, California, was abandoned, in part, because of hydraulic overloading at a rate of 13.4 in./wk. A loading of about 4 in./wk would seem to be the upper limit for a true irrigation system.

Nitrogen Loading Rates - One of the aspects of wastewater disposal that needs further investigation is the nitrogen loading. The soil can eliminate some of the nitrogen, and the crops can utilize some of the nitrogen, but nitrates

Table 4. Loading Rates Versus Soil Type and Crop

Location	Loading rate, in./wk	Soil type	Method of application	Crop
Infiltration-percolation				
Eglin AFB, Florida	11.2[a]	Sand	Spraying	Forest
Quincy, Washington	7.2[a]	Silty sand	Flooding	Corn, wheat
High irrigation[b]				
Hanford, California	4.2	Sandy loam	Flooding	Corn, oats, cotton
Tallahassee, Florida	4.0[a]	Sand	Spraying	Corn, millet, sorghum, grass
San Bernardino, California	3.7[a]	Sand	Spraying	Grass
Hillsboro, Oregon	3.1[a]	Sandy loam	Spraying	Grass, forest
Moderate irrigation[b]				
Abilene, Texas	3.0	Clay loam	Flooding	Cotton, maize, coastal bermuda grass
Alamogordo, New Mexico	2.5	Silty clay loam	Flooding	Corn, oats, sorghum, alfalfa
Pleasanton, California	2.2[a]	Loam	Spraying	Grass
Light irrigation[b]				
Rawlins, Wyoming	1.5	Gravel	Flooding, spraying	Alfalfa
Bakersfield, California	1.2	Clay loam	Ridge and furrow, flooding	Cotton, corn, barley, alfalfa
Ely, Nevada	0.3	Sandy loam	Flooding	Alfalfa

a. Year-round rate.
b. High, 3 to 4 in./wk; moderate, 2 to 3 in./wk; light, <2 in./wk.

can still build up in the groundwater. The acceptable nitrogen loading rate depends on the type of soil and the type of crop. Some crops and their annual nitrogen uptake amounts are listed in Table 5.

To avoid adding excess nitrogen to the soil system, it may be necessary to limit the nitrogen loading to the amount that crops can assimilate. This may require a reduction in the liquid loading rate in some cases. Actual nitrogen loading rates found in this study in terms of pounds per acre per year of total nitrogen, and crops grown for different sites are listed in Table 6. To determine the nitrogen loading for St. Petersburg, for example, multiply the total nitrogen concentration (12 mg/L) by the annual liquid load (45.9 ft/yr) by a conversion factor of 2.7 for a product of 1,490 lb/acre/yr. As seen in this table, nitrogen loading rates can vary tremendously depending upon the nitrogen concentration in the effluent and the liquid loading rates. Comparing the higher loadings with the probable crop uptake indicates that excess quantities of nitrogen are being applied. At St. Petersburg the operation began in 1972 and no buildups have been reported. At Tallahassee, however, despite the fact that the 4.0 in./wk liquid loading rate is successful, a buildup of nitrogen over the 7 years of operation has been reported.

Table 5. Crop Uptake of Nitrogen

Crop	Nitrogen uptake, lb/acre/yr	Reference
Alfalfa	155-220	37
Coastal bermuda grass	480-600	95
Corn	155	37
Red clover	120	37
Reed canary grass	226	24
Soybeans	99-113	37
Wheat	62-76	37

Table 6. Existing Nitrogen Loading Rates

Location	Seasonal liquid loading rate, in./wk	Annual liquid load, ft/yr	Nitrogen loading rate,[a] lb/acre/yr	Crop
St.Petersburg, Florida	10.6	45.9	1,490	Grass
Tallahassee, Florida	4.0	17.3	467	Grass, corn, millet, sorghum
Golden Gate Park, San Francisco, California	1.0	2.5	337	Grass
Irvine, California	1.5	6.5	176	Citrus, vegetables
Oceanside, California	1.3	5.6	113	Alfalfa, corn, grass
Woodland, California	1.5	2.5	72	Milo
Calabasas, California	1.9	8.2	67	Alfalfa
Abilene, Texas	3.0	2.0	65	Cotton, coastal bermuda, maize
Laguna Hills, California	0.3	1.3	18	Grass

a. lb/acre/yr = concentration, mg/L x annual liquid load, ft/yr x 2.7.

Source: APWA and Metcalf & Eddy visits.

Organic Loading Rates – Organic loadings, if too high, can clog the soil and seal the surface. Loadings up to 30 tons of BOD/acre/yr have been satisfactorily applied on an experimental basis [123]. The periodic "drying out" time will aid aerobic decomposition of the organic matter and reopen the soil. The ratio of drying to wetting should be between 3 and 6 to 1.

Some selected organic loading rates in terms of pounds of BOD per acre per year for sites in operation in the United States are listed in Table 7. The highest loading is at Fresno, California, with 15.9 tons of BOD/acre/yr, and this is the only site listed in Table 7 with an acknowledged odor problem. Two of the cities in Table 7, Fontana, California, and Forest Grove, Oregon, irrigate successfully with primary effluent, while the other cities have secondary treatment or oxidation ponds.

Table 7. Existing Organic Loading Rates

Location	Organic loading rate,[a] lb BOD/acre/yr	Method of application	Resting period, days	Crop
Fresno, California	31,800	Flooding	--	Grass
Mesa, Arizona	6,900	Flooding	--	Sorghum, grass
Fontana, California	6,560	Ridge and furrow	12-18	Citrus, hay, grapes
Forest Grove, Oregon	6,080	Spraying	13	Grass
Santa Maria, California	2,170	Spraying	10	Alfalfa
Colton, California	1,040	Flooding	--	Corn, oats
Cheyenne, Wyoming	600	Flooding	40	Alfalfa, grass
Las Vegas, Nevada	450	Spraying	20	Alfalfa
Woodland, California	284	Flooding	12	Milo
Irvine Ranch, California	260	Spraying, ridge and furrow	--	Citrus, vegetables

a. lb/acre/yr = concentration, mg/L x annual liquid load, ft/yr x 2.7.

Source: APWA and Metcalf & Eddy site visits.

Land Requirements - Once the controlling loading rate has been established (usually liquid loading controls), the approximate acreage necessary for irrigation can be calculated knowing the wastewater flow rate. If winter irrigation is practiced, the reduced loading rate in that season will control the total irrigated acreage requirement. For emergencies, an alternate area for disposal should be available. If winter storage is planned, the area must be designed to receive the application of both the stored effluent and the daily occurring effluent the following year.

For spray irrigation, buffer zones should be included. Depending on the wind, the degree of isolation of the irrigation land, and the degree of disinfection given the wastewater, buffer zones have been found to vary from a row of trees and bushes to an open area 200 feet wide.

For surface irrigation, buffer zones are less critical. At Woodland, California, and Abilene, Texas, for example, there are no buffer zones, and at Abilene several residences are within the boundary of the irrigation system.

Drying Period - The frequency of application of wastewater and the resting or drying out period for a soil will depend on the evapotranspiration, the amount of rainfall, and the crop. The application rate for most irrigation sites is between 1 and 4 in./wk. The hourly rate for spray irrigation is usually 0.16 to 0.40 in./hr. At these rates, the weekly liquid requirement can generally be applied in 1 or 2 days, and the remainder of the week can be a rest period. Drying periods may range from 1 to 14 days but are typically 5 to 10 days [45].

The rest period gives the bacteria time to break down the organic matter, and it gives the water time to percolate deep into the soil. In this manner, the soil will not become saturated and aerobic conditions will remain. The time between applications also gives the soil bacteria time to decompose and mineralize the nitrogen compounds in the soil. There are systems in which the infiltration rate remains acceptable after 60 years of operation.

Rest times for flooding or ridge and furrow operations should be longer than for spray irrigation because of the nature of the loading. The wastewater for these operations can have more and larger solids than for the spray irrigation method. The higher organic loading requires a longer treatment time for the soil bacteria. The rest period can be as long as 6 weeks but is typically 7 to 14 days [133].

Crops – The crop selection can be based on various factors: high water and nutrient uptake, high salt tolerance, high market value, or low management requirements. A listing of crops and their peak uptake rate for different areas of the country is given in Table 8 [115]. The high uptake crops such as grass, which require little maintenance during the growing season, represent good selections for cover crops. Another factor is the need for annual planting. With perennials, such as grasses, planting has to be done only once and the crop is established for years. With vegetable crops, the planting has to be done every year which increases the operational cost. Also, most vegetable crops require care during the growing period so that a marketable product is produced.

Table 8. Moisture-Extraction Depth and Peak-Period Consumptive-Use Rate for Various Crops Grown on Deep, Medium-Textured, Moderately Permeable Soils [115]

	A California (San Joaquin Valley)		B Texas (southern high plains)		C Virginia (coastal plain)		D Nebraska (eastern part)		E Wisconsin (state)	
Crop	Depth, in.	Use rate, in./day	Depth, in.	Use rate, in./day	Depth, in.	Use rate, in./day	Depth, in.	Use rate, in./day	Depth, in.	Use rate, in./day
Corn	60	0.26	72	0.30	24	0.18	72	0.28	24	0.30
Alfalfa	72	.25	72	.30	36	.22	96	.27	36	.30
Pasture	24	.32	42^a 72^b	$.25^a$ $.30^b$	20	.22	48	.29	24	.20
Grain	48	.17	72	.15			48	.26	18	.25
Sugar beets	72	.22					48	.26	18	.25
Cotton	72	.22	72	.25						
Potatoes	48	.24			18	.18	36	.26	18	.20
Deciduous orchards	96	.21			36	.22			36	.30
Citrus orchards	72	.19								
Grapes	72	.18								
Annual legumes			48	.18						
Soybeans							60	.27	18	.25
Shallow truck									12	.20
Medium truck					18	.16			18	.20
Deep truck									24	.20
Tomatoes					24	.18			18	.20
Tobacco					18	.17				
Rice										

a. Cool-season pasture.
b. Warm-season pasture.

Nutrients removed by plants can be divided into two groups, the essential nutrients and the trace nutrients. The essential elements, such as nitrogen, phosphorus, and potassium, are normally found in adequate quantities in municipal wastewater. The trace elements, such as the heavy metals, may or may not be present in the wastewater.

Salt tolerance can be an important parameter in crop selection. A salt buildup in the soil can be toxic to plants or can stunt their growth and produce a poor crop. A listing of forage and field crops and their tolerance to salts and boron is given in Table 9 [130]. Bermuda grass can tolerate 18,000 micromhos/cm, while ladino clover suffers a 50 percent decrease in yield with 2,000 micromhos/cm.

An adequate time for harvesting of crops must be scheduled into the design of the irrigation system. If farm machinery is used, the ground must be able to support the vehicles. California health regulations require a period of 30 days between the last irrigation with wastewater and harvesting of many edible crops. The harvesting of grasses requires drying times after cutting unless silage is being produced.

Distribution System – The distribution system for crop irrigation consists of four elements: transmission to site, distribution to outlets, outlet configuration, and controls.

The transmission to the site can be by pressure or by gravity. The size of the pipe will determine the headloss to the laterals and therefore the pumping head required to maintain a pressure at the lateral at design flow. The extra cost of a larger pipe is balanced against the savings in pumping costs to determine the most economical size.

Velocities in the transmission main should be between 2 and 10 fps. Gravity mains should be at the low end of the range, and pump mains should be in the middle to upper range. Where velocities are too high, excessive losses occur at bends and valves.

The quantity and pressure of the water are the main considerations in choosing the correct pipe material. Other factors to be considered are permanency of the system, rigidity, weight (if portable), corrosion, and friction factor. Where high pressures are involved, the results of hydraulic analysis for surges and water hammer must be designed into the system to prevent pipe breakage.

Distribution for spraying is through pressure pipes or laterals that run from the transmission main out into the field. The laterals are designed to carry the required

Table 9. Relative Tolerances of Field and Forage Crops [130]

To salt or electrical conductivity[a]		
Tolerant (partial listing)	Semitolerant (partial listing)	Sensitive (complete listing)
Barley	Alfafa	Alsike clover
Bermuda grass	Corn (field)	Burnet
Birdsfoot trefoil	Flax	Field beans
Canada wildrye	Oats	Ladino clover
Cotton	Orchard grass	Meadow foxtail
Rape	Reed canary grass	Red clover
Rescue grass	Rice	White Dutch clover
Rhodes grass	Rye	
Sugar beet	Sorghum (grain)	
	Sudan grass	
	Tall fescue	

To boron[b]		
Tolerant	Semitolerant	Sensitive
Sugar beet	Acala cotton	Fruit trees
Alfalfa	Pima cotton	Grapes
	Barley	Citrus
	Wheat	
	Corn	
	Milo	
	Oats	
	Pumpkins	

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a. Tolerant – 10,000-18,000 μmhos/cm;
semitolerant – 4,000-12,000 μmhos/cm;
sensitive – 2,000-4,000 μmhos/cm.

b. Plants are listed in the order of their tolerance.

flow of water to the outlets and maintain the necessary pressure. The pressure variation between the first and last sprinkler outlet should be less than 20 percent.

The design of laterals is as complex as the design for transmission mains. At each outlet the flow is reduced by the outlet discharge and the pressure is also reduced. The lateral must be designed to maintain the same pressure at each outlet so that the distribution pattern is uniform. A lack of uniformity will cause wet spots and dry spots.

The design of laterals should begin at the most distant lateral and progress backward to the transmission main. The design flow is added at each outlet, and the friction losses are computed back to the main.

Some of the factors that affect sprinkler performance are: nozzle design, pressure, jet angle, sprinkler rotation, overlap of sprinkler patterns, wind, riser height, and application rate. All of these factors have to be considered when a sprinkler system is designed, and more detailed information is available [89, 118].

The sprinkler spacing can vary from 20 to 120 feet depending on the pressure and flow rate. The sprinklers for permanent systems are usually placed on a square or rectangular pattern. Moving systems have a spacing only along the lateral, and the movement of the lateral eliminates the other dimension.

The control of systems can vary from hand operated valves, such as sluice gates, to electrically or pneumatically operated types. Most systems use hand operated controls as the sophistication of remote-controlled equipment is generally not warranted.

A clock timer may be employed to switch the use of laterals, and flow measuring devices are also used for more accurate applications. The usual economy-oriented design is used in municipal work where man-hours are balanced against equipment costs.

For flooding and ridge and furrow irrigation systems distribution may consist of open ditches, buried pipe with riser outlets, or gated pipe. A low velocity is preferred to prevent erosion.

Seasonal Changes

Provisions for seasonal changes must be considered in the design of a system. If the crop is harvested, a winter cover crop should be planted if possible. Systems currently in operation, such as the one at Bakersfield, California, continue through the winter months even though crop production is low. A year-round crop, such as permanent pasture, is used at Bakersfield to receive most of the wintertime flow. At sites where freezing is a problem, continuous operation results in a coating of ice on everything. This may not adversely affect trees [90], but it will reduce the degree of wastewater renovation. Annual rainfall and storm intensities should also be considered in the design, particularly with regard to confinement of runoff.

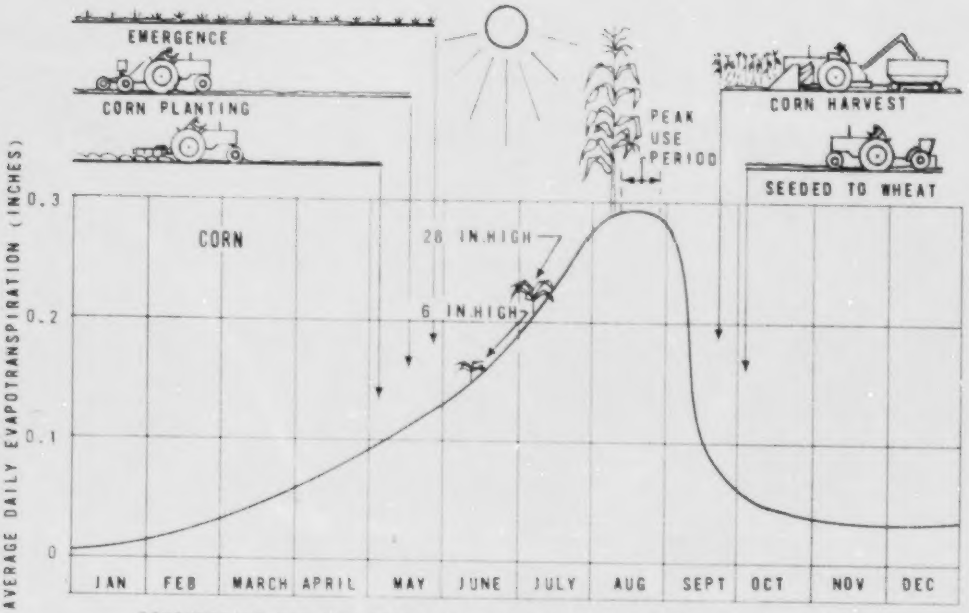
Storage of wastewater is required in areas where the freezing temperatures do not permit winter operation and may be needed in other areas for periods of harvesting and planting. The storage space must be planned for at the beginning of operation if no other disposal method is available. In climatic Zone E (see Figure 10 in Section VII), it is estimated that 3 to 6 months' storage may be required. In climatic Zone D only 10 to 60 days' storage may be required. The storage must be great enough to handle the future as well as present flows. When the operation begins in the spring, the stored volume must be applied to the land in addition to the daily occurring flow. Where land is at a premium, storage may be a limiting parameter.

MANAGEMENT AND OPERATION

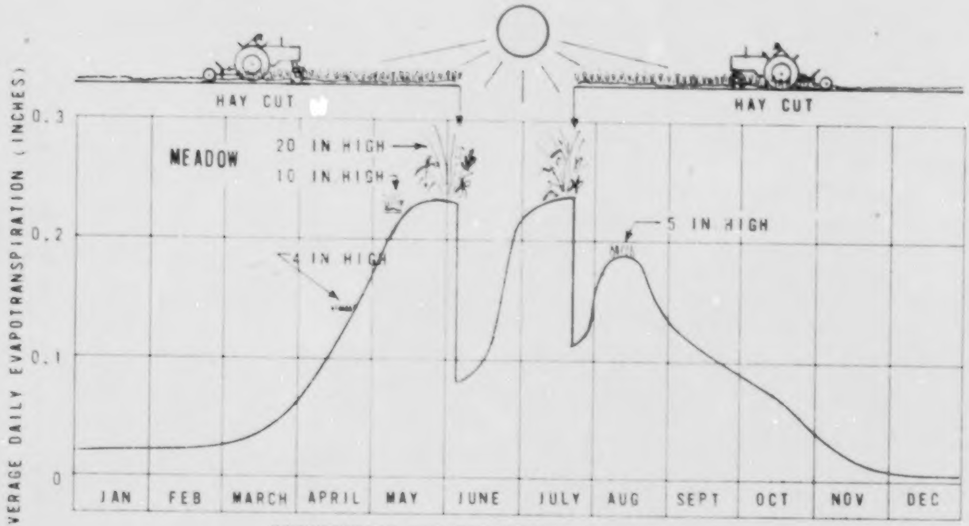
The management of an irrigation system is as important as the site selection and system design. It is vital that management personnel have a working knowledge of farming practices as well as principles of wastewater treatment. Important items in management include seasonal (often weekly) variation in operation, monitoring to establish removal efficiencies and to forecast buildups of toxic compounds, and ongoing observation of the system to avoid problems of ponding, runoff, or mechanical breakdowns.

Seasonal Variation in Operation

The operation of a crop irrigation system must adjust to the changing demands of the crops. Examples of water demand for corn and alfalfa throughout the growing season are shown on Figure 7. As shown, the rate of evapotranspiration increases as the plants grow until a peak is reached. The rate then begins to drop until the crop is harvested. At this point an alternate plot of land must be irrigated until harvesting and land preparation are complete and a second crop is planted. In climates that are warm enough, some crops can be grown throughout the year. In cooler climates



CONSUMPTIVE USE FOR YEAR 1953 WITH CORN, FOLLOWED BY WINTER WHEAT



CONSUMPTIVE USE FOR YEAR 1955 WITH IRRIGATED
FIRST YEAR MEADOW OF ALFALFA, RED CLOVER, TIMOTHY

FIGURE 7
AVERAGE DAILY CONSUMPTIVE USE FOR IRRIGATED
CORN AND MEADOW AT COSHOCTON, OHIO. [115]

where crops will not grow in winter, the wastewater must be either stored or applied to the bare ground and allowed to percolate into the ground.

The nutrients available from the wastewater are fairly constant throughout the year; however, crop demands can vary. A crop such as grass has a fairly uniform nutrient requirement during the growing season; however, corn and cotton need nutrients only at certain times. Since nearly constant amounts of nutrients are added to the soil, nutrients can build up and lead to future groundwater contamination when there is little or no crop uptake.

Solids buildup is another potential problem area for site irrigation. Application of wastewater with high solids content to the soil in winter when soil bacteria are less active may lead to a buildup of solids on the surface. When warmer weather occurs and the ground thaws the greatly increased microbial activity can result in a temporary odor problem.

Operational Problems

Problems that have occurred in operating land disposal sites are of two types: mechanical breakdown, and weather or climatic. The mechanical problems include pump breakdowns, sprinkler nozzle plugging, power loss, and piping breaks.

Some piping breaks have been due to freezing of the liquid in the pipe. Installation of drains will eliminate this problem if the drains function properly. Other climatic problems are functions of the eccentricities of nature--a wet or dry season, hot or cold spells. They must be expected and dealt with as they occur.

No matter how well designed an irrigation system is it will not function well without proper management. Even with automated systems there should be an observer present daily to ensure a smooth operation. With manual systems, full-time operators are required. If municipalities are operating the systems, the operators must be knowledgeable in agricultural management practices. The need for competent farm management cannot be overstressed.

Monitoring

Monitoring of the variables involved in the operation of a wastewate irrigation site should be conducted periodically to ensure reliable operation. These variables are climate, soil, soil water, groundwater, and crops.

The climatological data are available from the U.S. Weather Bureau for any area; however, local conditions may vary from the Weather Bureau data if the measuring station is very distant from the irrigation site. A local station measuring rainfall, temperature, and wind data would be helpful to augment the government data.

On the basis of this study it is concluded that the soil and soil water should be sampled at least twice a year to determine needed nutrients or disclose a buildup of any substance that would be harmful to crop production. Samples should be taken from several parts and depths of the site to get a representative sample of the soil conditions.

The groundwater should be monitored by sample wells throughout the year. A well should be placed in each possible direction of groundwater movement [18]. A sampling site must be established where the groundwater enters the site so that a comparison can be made or contamination discovered.

Samples of the crops should be taken during the growing season to determine if there are any deficiencies in the crop uptake. Instruments are available to measure the moisture deficit of crops in place by electronic means. Tests for specific elements require the removal of leaves and stems for laboratory analysis.

Analysis - The climatological data should be analyzed to obtain weather patterns so that the most efficient crop operation can be established. High amounts of rainfall may require lower wastewater application rates in order that the soil does not become waterlogged. Temperature patterns can be used to determine statistically when killing frost first occurs and when planting can be done with relative safety. Also, the length of the growing season can be determined from the data, and the best selection of crop or combination of crops can be made for that length of time. Wind patterns will affect spray distribution and, at times, will prohibit spraying altogether.

On the basis of this study it is suggested that the minimum parameters to be analyzed should include pH, nitrogen, potassium, phosphorus, and conductivity of the soil and soil water. The SAR should be checked annually. Levels of plant-harming elements, such as boron, should also be analyzed periodically. The constituents of the wastewater will indicate which elements to test for to avoid a buildup of any harmful substances.

The groundwater should be monitored and analyzed for bacteria, nitrogen, and TDS increases. A comparison between the groundwater quality above and below the site will give the best indication of contamination.

The crops need to be analyzed only when a deficiency or problem appears in the growth. Since the irrigation is done on a regular schedule, there should be no problem with low water content.

Reporting - At the present time, very few states require a report of monitoring results. In California, this requirement resides with the Regional Water Quality Control Boards. A report is required if the quantity or quality or the mode of operation is changed from the originally approved method. Periodic reporting is required only if the Regional Board so states at the time the application for a disposal site is processed and approved.

As the process of land application becomes more widespread, more regulations will be made to control it and requirements for increased reporting of monitoring results will result. The results of tests discussed in this section should be the minimum required for reporting.

Treatment Efficiency

The treatment efficiency of a crop irrigation site is the highest of all the types of land application. The major reasons are the removal of nutrients by the crop and the relatively low application rates. The removal of organic matter will be satisfactory as long as the infiltration rate is maintained and the soil does not become clogged. As shown in Table 10, the removal of BOD is 95 percent or more and the removal of suspended solids under proper operation should be 97 percent or more.

The nutrient uptake efficiency will vary with the crop growth. As the crop develops, the use of nutrients will increase; if the application of nutrients is not as high as the uptake, the nutrients will be taken up from the soil or a deficiency will result. A balance must be established between the amount of nutrients applied or in the soil and the uptake of the crop. Values of crop uptake for various elements in pounds per acre are given in Table 11. In Arizona, crop uptake accounted for 75 percent of the applied nitrogen, 90 percent of the applied phosphorus, and 60 percent of the applied potassium [112].

Enteric organisms are almost completely removed by the soil [40, 41, 138] provided that aerobic conditions are maintained. The removal efficiency for E. Coli is reported

Table 10. Removal Efficiency at Selected Sites

Location	Loading rate, in./wk	Removal efficiency, %					Reference
		BOD	SS	N	P	E. Coli	
Lake Tahoe, California[a]	13.4	--	--	56	91	96[b]	36
Cincinnati, Ohio[c] (sand)	11.2	95	--	20	30	--	10
Cincinnati, Ohio[c] (silt loam)	11.2	95	--	50	96	--	10
Cincinnati, Ohio[c]	11.2	--	--	85	99	--	106
Pennsylvania State University[d]	4.0	98	99	91	99	99	90
Melbourne, Australia[e]	1.3	98	97	90	80	98	51

a. Data on runoff during 1964; operation ceased in 1968.
b. Removal from chlorinated secondary effluent.
c. Experimental outdoor lysimeters 6 ft deep at Taft Sanitary Engineering Center.
d. Removals from secondary effluent at 3-ft depth.
e. Removals from raw wastewater at 4- to 6-ft depth.

Table 11. Plant Uptake of Selected Elements [133]

Plant	Uptake of elements, lb/acre/yr											
	N	P	S	B	K	Ca	Na	Mg	Fe	Mn	Zn	Cu
Alfalfa	220	21	16	0.6	120	150	3	15	0.9	0.5	0.3	0.1
Corn	155	25	18	0.4	52	21	7	23	1.4	1.4	0.6	0.1
Potatoes	200	16	10	--	220	52	3	4	--	--	--	--
Red clover	126	13	9	0.2	81	92	4	22	1.0	0.6	0.3	0.1
Reed canary grass	226	36	--	9.4	--	69	61	3.8	17	--	--	--
Soybeans	110	18	10	0.1	48	26	--	15	0.6	0.2	--	0.03
Wheat	76	14	11	0.3	42	12	1	8	0.7	0.5	0.2	0.03

to be between 98 and 99 percent. Bacteria travel only a few feet in the unsaturated soil zone [53, 55, 104], but they can travel a few hundred feet in groundwater flow [108].

As most irrigation soils are loamy, they have a considerable capacity for retention of metals by ion exchange and adsorption. Most toxic substances are applied in very small quantities so that the soil can remove them efficiently. Continuous sampling of both the wastewater and the soil will alert the operator of the site to any buildup problems.

ENVIRONMENTAL EFFECTS

Effects on the physical environment from wastewater irrigation include those on the climate, soil, vegetation, groundwater, and air. Effects on human and animal life are described under "Public Health Considerations."

Climate

As will be shown in a later section (VII), the effects of irrigation on the climate are limited to extreme local conditions. Air passing over the site will pick up moisture and will be cooled or warmed, but within a few hundred feet downwind from the site, original conditions will exist. Studies were made on large (1-million acre) lakes in Russia, and the data collected over 25 years show very localized effects [132].

Soil

Soil is affected greatly by the application of wastewater, and in many cases the effects are beneficial. Soil fertility is increased by the addition of nutrients. Soil tilth or friability is increased by the addition of organics, and in some cases, excess sodium conditions have been corrected. For example, at Woodland, California, alkali soil that was practically impermeable to rain and unacceptable for commercial irrigation purposes, has been partially renovated by wastewater application. Although the soil is still alkaline, wastewater will percolate into it at moderate rates.

Soils used in irrigation have considerable organic and clay contents so that retention of phosphorus, fluoride, metals, nondegradable organics, bacteria, and viruses takes place to a great extent. Also, irrigation depends upon evaporation for removal of a considerable portion of the applied wastewater, and this process concentrates the constituents that remain in the water. As a consequence plant toxicity that is due to buildup of metals and TDS can develop. Phytotoxic concentrations of copper and zinc have apparently accumulated in the soil at two sewage farms in France, but it has taken over a century for them to develop [125]. Phytotoxic levels of TDS can be remedied by leaching (adding excess irrigation water).

Vegetation

The application of wastewater to crops is very beneficial because of the natural fertilizers and nutrients in the liquid. Virtually all essential plant nutrients are found in wastewater. Measurements made at Pennsylvania State University [49, 90] show that the crop yield increases when wastewater rather than ordinary water is used for irrigation. Hay yields increased as much as 300 percent, corn grain increased 50 percent. The increased yields of crops under varying application rates of municipal wastewater are given in Table 12.

The nutrients derived from wastewater are nitrogen, phosphorus, potassium, lime, trace elements, and humus. Nitrates can be utilized by growing plants. By applying wastewater intermittently, nitrogen will be converted to the nitrate form and will be fully available to crops during the growing season.

Calcium in the form of lime is an indirect fertilizer that neutralizes acidity and checks some plant diseases. Soils high in organic matter, such as muck and peat, are generally deficient in calcium as are clayey soils. Calcium in sewage exists in the form of carbonate, which is favorable to important soil organisms. Trace elements in wastewater are sulfur, magnesium, iron, iodine, sodium, boron, manganese, copper, and zinc. These elements can be helpful in plant development; however, in high concentrations, they can be toxic.

Toxic elements can be toxic either to the plants or to the animal that consumes the crop. Analysis of the soil and of the crop itself will give the levels of concentration of any toxic elements so that proper crops can be selected. Certain crops have a higher tolerance for toxic substances than others. An example is oats and flax with respect to nickel. Oats have a high tolerance at 100 mg/L, while flax has a low tolerance at 0.5 mg/L [133].

The uptake of a toxic substance, like lead, into the edible portions of the plant has been studied to determine soil concentrations necessary to create toxic conditions.

Table 12. Crop Yields at Various Levels of Wastewater Application [49]

Crop	Unit	0 in./wk		1 in./wk		2 in./wk	
1963							
Wheat	bu/acre	48		45		54	
Corn	bu/acre	73		103		105	
Alfalfa	tons/acre	2.18		3.73		5.12	
Red clover	tons/acre	2.48		4.90		4.59	
1964							
Red clover	tons/acre	1.76		5.30		5.12	
Corn	bu/acre	81		121		116	
Corn stover	tons/acre	3.58		7.29		8.48	
Oats	bu/acre	82		124		97	
1965							
Alfalfa	tons/acre	2.27		4.67		5.42	
Corn	bu/acre	63		114		111	
Corn silage	tons/acre	3.11		3.93		4.32	
Oats	bu/acre	45		80		73	
Reed canary grass	tons/acre	--		--		6.13	
1966							
Alfalfa	tons/acre	1.95		3.86		4.38	
Corn	bu/acre	18[a]	33[b]	115[a]	98[b]	140[a]	115[b]
Corn silage	tons/acre	2.75[a]	2.47[b]	9.02[a]	4.45[b]	7.53[a]	5.68[b]
Reed canary grass	tons/acre	--	--	--	--	4.32[a]	--
1967							
Corn	bu/acre	93[c]	87[d]	96[c]	79[d]	116[c]	80[d]
Corn silage	tons/acre	4.67[c]	--	4.47[c]	--	4.42[c]	--
Reed canary grass	tons/acre	--	--	--	--	7.03[c]	--

a. 19-in. row.
b. 38-in. row.
c. 20-in. row.
d. 40-in. row.

Bromegrass grown in soil with as high as 680 mg/L of lead had only 34.5 mg/L of lead in the leaves [133]. This is well below the 150 mg/L level of toxicity to cattle and horses and caused no detrimental effects on the plants [133].

The plants will not be harmed by pathogenic organisms but animals that consume the plants could be harmed. Organisms can enter plants through bruises or cuts but generally they are not adsorbed by the plants.

Groundwater

Nutrients that are not used by plants or fixed in the soil can leach down to groundwater and cause contamination. The major element of concern is nitrogen. Nitrogen in the nitrate form is used by plants for the growth process. Nitrates that are not utilized are highly mobile and will leach down to the groundwater. If concentrations are high enough, the groundwater can become contaminated and unsuitable for domestic consumption. The U.S. Public Health Service Drinking Water Standards recommend a concentration limit of 10 mg/L for nitrate nitrogen.

Phosphorus in the wastewater may also leach to the groundwater if it is not used by the crop or fixed by the soil; however, this occurrence is rare in irrigation practice. Soils with appreciable organic or clay contents adsorb practically all of the phosphorus applied by wastewater irrigation.

Organics can appear in groundwater when there is a high application rate of wastewater or when there is an open soil, such as sand or gravel, with a high percolation rate.

Organics are usually broken down by microorganisms and used by plants. Even phenols and other hydrocarbons are acted upon by bacteria at slow rates. With open soils, the water carries the organics through the soil too fast for the bacterial action to take place. High concentrations of phenols can be toxic to the bacteria and therefore no removal will take place.

Toxic compounds can be changed by the chemical reaction of cation exchange and can be rendered nontoxic by bacteria under cometabolism [82]. Chemical precipitates that are formed can be leached out of the soil if a heavy loading occurs or if a significant decrease in pH occurs.

Enteric organisms usually do not reach the groundwater because they are removed or die out before the groundwater level is reached [53, 55]. Where crops are grown, the groundwater is usually kept low enough so that the organisms are eliminated from the percolating water before it reaches the groundwater.

The TDS concentration in the groundwater is affected by the leaching of minerals from the soil. The U.S. Public Health Service has recommended maximum level for TDS of 500 mg/L in public water supplies. An extreme example of the increase of TDS in groundwater occurred at Ventura in Southern California. The applied irrigation water had a TDS concentration of 1,702 mg/L and the test wells had concentrations of up to 8,128 mg/L [120].

Air

Spray irrigation has the inherent problem of aerosol travel of water. The higher the pressure at the nozzle, the finer the droplet and hence the longer the travel distance. Airborne pathogens are a matter of concern and study [110, 117] and will be discussed further under "Aerosols." Some irrigation sites have 50- to 200-foot buffer zones or rows of trees around the irrigation area so that the travel of the airborne droplets is limited within the site.

Odors caused by anaerobically decomposing organics can be troublesome. The positive solution to the problem is to eliminate the cause of the odors. An examination of the operating procedures may indicate an overloading of the soil, or an examination of the ground may indicate that the surface is sealed. Corrective action of extensive drying or surface scarifying to eliminate the cause of odors must be taken to avoid complaints.

PUBLIC HEALTH CONSIDERATIONS

Public health aspects are related to (1) the pathogenic bacteria and viruses present in municipal wastewater and their possible transmission to higher biological forms including man, (2) the chemical compounds present in wastewater that can cause health problems, and (3) the propagation of insects that could be vectors in disease transmission.

The passing of the Federal Water Pollution Control Act Amendments of 1971 and 1972 has drawn attention to the use of wastewater for irrigation. Stricter laws and regulations on water pollution and land application will undoubtedly be passed in the future.

Regulations by State Agencies

Each state has the legal power to protect the public health of its people. Each state can act separately and independently in making laws; however, the state legislatures do not generally have the time or technical competence to enforce the laws, so they delegate the authority to the state boards of health [23].

There is no uniform pattern to the regulations in the United States. In 1968, Coerver [23] indicated that 11 states had a specific policy toward sewage irrigation, while in 1972 at least 17 states had specific regulations [21]. The use of untreated sewage or primary effluent on vegetables grown for human consumption is generally prohibited. Some states allow the use of completely treated, oxidized, and disinfected sewage on fruits and vegetables which are eaten raw. Other states ban the use of any sewage effluent for irrigation of truck crops and vegetables. Milk cows may not pasture on sewage irrigated lands in some states, for fear of typhoid infection transmitted by udder contamination [111].

Most states have no specific regulations covering irrigation of crops with effluent. States with long histories of irrigation, such as Arizona and California, have recognized the need for this resource and have passed regulations controlling the use of effluents. Other states, with plentiful water supplies and no need for irrigation, have ignored irrigation of crops with effluent altogether [21]. The individual State Health Department should be contacted for specific land application regulations.

Survival of Pathogens

The survival of pathogenic bacteria and viruses on and in soil, in sprayed aerosol droplets, and on vegetables has received considerable attention. It is important to realize that any connection between pathogens spread on land during irrigation and the contraction of disease in animals or man would take a long and complex path of epidemiological events. Nevertheless, questions have been raised, concern exists, and precautions should be taken in dealing with the possible disease transmission.

Pathogens in Soil - The survival of pathogenic organisms in the soil can vary from days to months depending on the soil moisture, soil temperature, and type of organism. A listing of organisms and their reported survival times in soil, on crops, or in water is included in Table 13.

Table 13. Survival Times of Organisms [111]

Organism	Media	Survival time
Anthrax bacteria	In water and sewage	19 days
Ascaris eggs	On vegetables	27-35 days
	On irrigated soil	2-3 years
	In soil	6 years
B.dysenteriae flexner	In water containing humus	160 days
B.typhosa	In water	7-30 days
	In soil	29-70 days
	On vegetables	31 days
Cholera vibrios	On spinach, lettuce	22-29 days
	On cucumbers	7 days
	On nonacid vegetables	2 days
	On onions, garlic, oranges, lemons, lentils, grapes, rice and dates	Hours to 3 days
Coliform	On grass	14 days
	On clover leaves	12-14 days
	On clover at 40-60% humidity	6 days
	On lucerne	34 days
	On vegetables (tomatoes)	35 days
	On surface of soil	38 days
	At -17 deg C	46-73 days
Entamoeba histolytica	On vegetables	3 days
	In water	Months
Enteroviruses	On roots of bean plants	At least 4 days
	In soil	12 days
	On tomato and pea roots	4-6 days
Hookworm larvae	In soil	6 weeks
Leptospira	In river water	8 days
	In sewage	30 days
	In drainage water	32 days
Liver fluke cysts	In dry hay	Few weeks
	In improperly dried hay	Over a year
Poliovirus	In polluted water at 20 deg C	20 days

Table 13. (Continued)

Organism	Media	Survival time
Salmonella	On grass (raw sewage)	6 weeks+
	On clover (settled sewage)	12 days
	On vegetables	7-40 days
	On beet leaves	3 weeks
	On grass	Over winter
	On surface of soil and potatoes	40 days+
	On carrots	10 days+
	On cabbage and gooseberries	5 days+
	In sandy soil - sterilized	24 weeks
	In sandy soil - unsterilized	5-12 weeks
	On surface of soil (raw sewage)	46 days
	In lower layers of soil	70 days
	On surface of soils (stored sewage)	15-23 days
	In air dried, digested sludge	17 weeks+
Schistosoma ova	In digestion tanks	3 months
	In sludge at 60-75 deg F (dry)	3 weeks
	In septic tank	2-3 weeks
Shigella	On grass (raw sewage)	6 weeks
	On vegetables	7 days
Streptococci	In soil	35-63 days
	On surface of soil	38 days
S. typhi	In water containing humus	87-104 days
Tubercle bacteria	On grass	10-14 days
	In soil	6 months+
	In water	1-3 months
Typhoid bacilli	In loam and sand	7-17 days
	In muck	40 days
Vibrio comma	In river water	32 days
	In sewage	5 days

In relation to the survival of coliform organisms, some bacteria do survive for a longer time. Although the survival of viruses in soil has been essentially unexplored, there is evidence of their inactivation in soil [28, 33].

Aerosols – The travel time and distance of bacteria in air has been studied in the United States and in Europe. In the study reported by Merz [79] it is concluded that the bacterial travel is limited to the distance of travel of the mist from sprinklers. Sepp [111] reported that, in a German study, the bacteria traveled from 460 feet to 530 feet with a 6.7-mph wind velocity. It was estimated that the maximum travel would range from 1,000 feet to 1,300 feet with an 11-mph wind. Most of the mist and bacteria landed within half the maximum measured distance.

Low trajectory nozzles and screens of trees and shrubs can be used to limit bacterial travel. The traveling rig sprinklers designed for Muskegon, Michigan, have been modified to direct the spray trajectory downward. Studies of aerosol drift are being planned for the Muskegon operation [117].

Studies have been made on the favorable conditions for bacteria to live in aerosol particles. It was found that, as the relative humidity decreased and air temperature increased, the death rate of the bacteria increased [94]. Sorber [117] indicates that a 50-micron water droplet will evaporate in 0.31 second in air, with 50 percent relative humidity and a temperature of 22 deg C. Thus, dessication is a major factor in bacterial die-off.

Pathogens on Vegetables – In general, bacteria will not enter healthy, unbroken vegetables; however, broken, bruised, or unhealthy plants and vegetables are easily susceptible to attack by bacteria. The cleaning of vegetables with plain water, or detergents is ineffective as a means of bacteriological decontamination. Germicidal rinses of chlorine and its compounds are superior to water and detergents, but are unreliable. The only reliable method of decontamination is pasteurization at 60 deg C for 5 minutes [103].

Chemical Compounds

If certain chemical compounds reach the groundwater, they may present a health hazard should the groundwater be used as a potable water supply. Compounds that may reach the groundwater as a result of land application of wastewater include nitrates, TDS, and trace organics.

Nitrate nitrogen has been demonstrated to be the causative agent of methemoglobinemia in children. Ingested nitrate is reduced to nitrite in the digestive tract. The nitrites are then adsorbed into the bloodstream, ultimately causing suffocation of the child by reducing the ability of the blood to carry oxygen [133].

Irrigation with wastewater will normally increase the TDS content of the percolating water. In drinking water, high TDS levels can be harmful to people with cardiac, viral, or circulatory diseases [117].

Finally, the toxicity of certain constituents of the COD, often called trace organics, is of concern. The possibility of such compounds reaching the groundwater, however, is slight.

Insect and Rodent Control

The control of insects and rodents on a wastewater irrigation site is more critical than on a conventional irrigation site because of the possibility of contamination by bacteria from the wastewater. A three-year study at Pennsylvania State University revealed that the use of wastewater to irrigate the forested land had no adverse effect on the wildlife population. Gophers and muskrats can be a problem for flood irrigation or ridge and furrow sites by burrowing in the dikes. Such problems have been reported at Woodland, California, and Westby, Wisconsin. Trapping and other conventional methods of removal have arrested the problem. In the Pennsylvania State study, it was reported that mosquitoes increased in population mainly because of the wetter environment and the availability of standing puddles for breeding [90].

Mosquitoes will propagate in tepid water standing only a few days, which enforces the point about the necessity for drying periods between wastewater applications. Although mosquitoes may be controlled by use of insecticides, such practices may involve some degree of environmental degradation and usually serve only as a temporary solution.

IRRIGATION ABANDONMENT

In this assessment of the current state-of-the-art, an investigation was made into reasons for abandoning irrigation at selected sites. Selection was made of 24 sites in California and Texas and a number of interesting reasons were found for abandonment. Generally, the irrigation practice was abandoned when the city expanded its sewage treatment facilities and either changed plant locations or had inadequate land available to expand the irrigation system. A complete description of each case is given in Appendix B.

Irrigation with municipal wastewater was abandoned at many locations because of a variety of often interrelated reasons. Sometimes a single event, such as the death or retirement of a key manager, or the receipt of a complaint, will result in disenchantment of the city officials with irrigation as a disposal method. Limits of liquid, organic, and nitrogen loadings, land use changes, political and environmental changes, and improper management will be discussed as reasons for irrigation abandonment.

Limits of Loading

The soil system may become overloaded with water, organics, nitrogen, or toxic substances. A survey conducted in 1934 and again in 1937 found that in the interim six cities had abandoned irrigation: two because of inadequate infiltration rates; two because of insufficient land; one because of high alkali in the soil; and one because of high salt in the wastewater [47].

Liquid Loading – The upper limits of loadings depend upon the soil type and crop requirements or tolerances. As indicated under "Design Criteria," 4 in./wk is the dividing line between the classifications of irrigation and infiltration-percolation. At Quincy, Washington, a rate of 7.2 in./wk is being applied to corn and wheat. This rate results in occasional drowning of the crops and the City plans to expand its acreage. An irrigation rate of 4.3 in./wk on loamy soil at Orland, California, was excessive and the result was irrigation abandonment in 1964.

Organic Loading – The upper limits of organic loadings are rarely approached in wastewater irrigation practice. A figure of 30 tons/acre/yr has been found to be a satisfactory loading for septic tank effluent [123]. The highest loading determined from this study for municipal effluent was 15.9 tons of BOD/acre/yr at Fresno, California; however, odor problems have resulted. The upper limits of organic loadings will more likely be tested by land application of sludge or industrial wastewater.

Nitrogen Loading – Despite the low hydraulic loading at Lubbock, Texas, the nitrogen loading of only 310 lb/acre/yr has resulted in a fourfold buildup of nitrates in the groundwater over 40 years [136]. In a northern Michigan forested area, liquid applications of 2.5 in./wk in loamy sand have been satisfactory, except for a high nitrogen buildup. The buildup occurred with a nitrogen loading of 170 lb/acre/yr after one year of operation [129]. At South Lake Tahoe, California, the runoff of approximately 50 percent of the influent nitrogen was a significant factor in abandonment of land application.

Toxic Buildup – Buildup of TDS, sodium, and heavy metals in the soil can cause site abandonment. Leaching, or the addition of soil amendments, may alleviate the toxicity; in the case of TDS or boron, a more salt tolerant crop may be found. At Kingsburg, California, the presence of cannery lye peeler waste has led to irrigation abandonment. It has been reported that, in France, phytotoxic levels of copper and zinc have built up in the soil, but it has taken over 100 years for this to occur [125].

Land Use Changes

Changes in land use patterns can have a serious effect on irrigation projects. Increased population around the sewage treatment plant at Pasadena, California, led to odor complaints and the abandonment of the plant. In the case of the Talbert Valley Water District in Southern California where over 2,800 acres were being irrigated in 1957, the land use changed so rapidly from agricultural to residential that the District was out of business by 1964.

A form of urbanization that can cause the abandonment of a site is the change of location of the treatment plant. Many towns as they grow find that the existing treatment plant is too small and the treatment is inadequate. Often, when a new plant is constructed, a new location is selected and the existing irrigation system is eliminated. The town of St. Helena, California, built a new treatment plant and ended a wastewater irrigation system that had been in operation for over 60 years. The town of Ukiah, California, also built a new treatment plant at a new location, thus terminating the irrigation practice.

Political and Environmental Changes

The regulations passed in most states against irrigation with untreated sewage caused the abandonment of many sewage farms. Requirements for increased levels of treatment prior to land application may also lead to irrigation abandonment.

An environmental change that could cause abandonment is groundwater degradation. The buildup of nitrates or salts in the groundwater can make it unsuitable for consumption. If requirements are imposed on wastewater irrigation which define groundwater pollution as the increase in any constituent above the U.S. Public Health Service limits for drinking water, increased monitoring and groundwater table control will be necessary.

Where water is scarce, the application of treated effluent to the land, with subsequent loss to evaporation and the groundwater, serves to reduce summer stream flows. In streams where treatment plant effluent represents a major portion of the summer flow, other water uses, such as fish propagation and recreation, may be augmented by stream discharge instead of land application. At Childress, Texas, discharge to a dry creek in the summer was a satisfactory method until one farmer periodically withdrew the wastewater for irrigation. The resultant ponding and odor complaints led to discharge to a different creek.

Lack of Management

The lack of competent management has resulted in the abandonment of many irrigation systems. In Augusta, Maine, the death of the chief operator ended the use of irrigation. Similarly, in Stamford, Texas, it was the retirement of the chief operator that ended the use of irrigation. It is not clear whether other systems, abandoned for various reasons, could have remained viable under competent and forceful management.

The lack of a satisfactory arrangement between owner and lessee has resulted in system abandonment [47]. It appears that a voluntary system at Woodland, California, where the farmer calls for the irrigation water when he needs it, works well. The system at Woodland has the flexibility of discharging to percolation basins, duck ponds, or holding ponds when the lessee is not irrigating. On the other hand, voluntary irrigation has been a failure at Fresno, California.

SECTION V

INFILTRATION-PERCOLATION OF MUNICIPAL WASTEWATER

Land application of municipal wastewater by infiltration-percolation is often referred to as groundwater recharge because the major portion of the wastewater applied infiltrates the soil surface, percolates through the soil matrix, and eventually reaches the native groundwater. The wastewater is renovated as it travels through the soil matrix by natural physical, chemical, and biological processes. Depending upon its final quality, the recharged water may be recovered and used for irrigation, recreation, or municipal or industrial supply.

The feasibility of this approach has been demonstrated by systems operating at Hemet, California [119], Phoenix (Flushing Meadows), Arizona [100], Whittier Narrows, California [69], and Santee, California [77]. These systems, which have been well studied, represent examples of planned land treatment and recovery. Other systems, such as those at Lake George, New York [6], Vineland, New Jersey, Marysville, California, and Westby, Wisconsin [10], represent examples of direct recycling of effluent to the land by infiltration-percolation. The scope of this section includes both types of systems, but major emphasis is placed on engineered systems involving groundwater recharge. The purpose of the discussion is to identify and evaluate approaches currently used for the location, planning, design, and operation of such systems. As in Section IV, the major topics covered include (1) system design, (2) management and operation, (3) environmental effects, (4) public health requirements, and (5) analysis of system failures.

SYSTEM DESIGN

The elements of system design include site selection and criteria for wastewater pretreatment, loading rates, type of basin surface, and recovery.

Site Selection

The most important factors in site selection are soil drainability and the movement, level, and quality of groundwater. Other related selection factors include soil type and depth, underlying geologic formations, and surface topography.

Soil Characteristics – Soils with infiltration rates on the order of 4 to 12 in./day or more are necessary for successful use of the infiltration-percolation approach. Acceptable soil types include sand, sandy loams, and loamy sands and gravels. Very coarse sand and gravel is not ideal because it allows wastewater to pass too rapidly through the first few feet where the major biological and chemical action takes place. A silt loam soil has been utilized with some success in Westby, Wisconsin, with an annual loading of up to 45 feet (10.4 in./wk) [124]. Recently, loadings have been reduced to 8.4 in./wk but prolonged rains have continued the overloaded conditions.

Of equal importance to infiltration rates of the topsoil are the percolation rates of lower soil layers. Permeability, either horizontal movement or vertical percolation, must equal or exceed infiltration rates.

The depth of soil layers and the permeability of each layer will affect the overall percolation rate. The system may be limited by the presence of a shallow clay layer between two sandy layers. The high permeability of the lower layer will be effectively negated by the presence of such a clay lens. Soil borings must be taken at a site to obtain the soil profile. A site with extensive clay layers, or other impermeable formations near the surface, should be rejected as a possible site.

Hydrologic Conditions – The depth, movement, and quality of groundwater are the most important hydrologic factors in site selection. Wastewater percolating through soil will create a mound or pseudo-water table as shown on Figure 1 in Section III. If the normal water table were less than 10 feet from the surface, the recharge mound would likely intersect the surface with resultant ponding. A depth of 15 feet from surface to groundwater is considered a minimum for maintenance of long term liquid loading rates and effective renovation [124]. The movement of groundwater will be discussed along with aquifers under "Geologic Conditions."

The quality of the groundwater is critical, whether it is excellent or brackish. If it is of high quality, the recharge may degrade it, but if it is brackish, recharging could improve its quality. For example, the groundwater recharge operations at Hemet and Los Angeles (Hyperion), California, are effectively limiting salt water intrusion into the groundwater from the ocean. On the other hand, at Phoenix, where native groundwater quality is also poor, the recharge system is attempting to recover the renovated water before it mixes with, and is degraded by, the native groundwater.

Precipitation will add to the liquid loading, both directly as it falls and indirectly by increasing adjacent stream flows which leads to a general rise in the water table. At Hemet, heavy and prolonged rains led to ponding and temporary abandonment of recharging [124].

Geologic Conditions - The parent material of a soil is the original material, usually erodible rock such as soft sedimentary rock, from which the soil was created. The parent material will give the soil its chemical and mechanical properties. Knowledge of parent material and existing rock formations is important in assessing the water holding characteristics and transmissibility of a soil system.

The ability of a soil to transmit groundwater determines its suitability to act as an aquifer. An aquifer by definition is a geologic formation which contains water and transmits it from one point to another in quantities sufficient to permit economic development. In contrast, an aquiclude is a formation which contains water but cannot transmit it rapidly enough to furnish a significant supply to a well or spring.

A soil with high porosity does not necessarily make a good aquifer. Porosity is the ratio of pore or void volume to the total volume. The more accurate measure of the potential of a soil type is the specific yield. The specific yield is the ratio of water that will drain freely from the material to the total volume of the material. Soil types and their hydraulic characteristics as aquifers are given in Table 14. Most of the productive aquifers in the United States are of the sand and gravel type.

Minimization of the spread of renovated water into an outside aquifer can be accomplished by surrounding the system with wells or drains to interrupt the flow. Evaluating the hydraulics of groundwater flow is an area of increased computer use and modeling. At Flushing Meadows, the horizontal and vertical conductivities were calculated by use of an electrical resistance network analog [14].

Table 14. Soil Types and Hydraulic Characteristics [60]

Material	Porosity, %	Specific yield, %	Permeability, gpd/sq ft[a]
Clay	45	3	1
Sand	35	25	800
Gravel	25	22	5,000
Gravel and sand	20	16	2,000
Sandstone	15	8	700
Dense limestone	5	2	1
Granite	1	0.5	0.1

a. The permeability shown is the discharge in gallons per day through an area of 1 sq ft under a gradient of 1 ft/ft at 60 deg F [60].

Topography – The site topography can be adapted to suit infiltration-percolation site requirements. Since high rate disposal is desired, ponding or flooding the basin is the usual mode of application. A site should be flat or gently sloping so that it can be diked into basins. Too much slope would create lateral percolation which could affect the percolation rates of the lower basins. At Westby, Wisconsin, basins have been terraced into a 5 percent sloping hillside, but there is some effect of lateral percolation.

Design Criteria

In the design of an infiltration-percolation system, the important criteria are (1) wastewater quality and pretreatment requirements, (2) liquid and organic loading rates, (3) type of basin surface, (4) distribution system, (5) provisions for seasonal changes, and (6) renovated water recovery.

Wastewater Quality and Pretreatment Requirements – The quality of wastewater to be applied to a spreading basin is considered a design parameter because it directly affects the land area required and the operation and management of an infiltration-percolation system. The principal concern is the determination of the quality of wastewater that may be used without seriously reducing natural infiltration capacity and without degrading groundwater quality.

The major quality factors affecting the infiltration capacity of a system are the concentration of suspended solids and organic material. These wastewater constituents hasten the clogging of the soil surface through several complex mechanisms. Surface pore space is reduced by deposition of suspended solids and bacterial growth associated with the presence of organic material. As a result, the diffusion of oxygen into the soil is reduced. Unless the pore space is reopened and aerobic conditions are maintained in the soil through periodic drying of the spreading basin, anaerobic bacterial activity will begin. This activity, with its insoluble slimes as byproducts, is the major cause of severe soil clogging [65]. The result of the clogging phenomena associated with suspended solids and soluble organic material is that the quality of the water in terms of these constituents will dictate the length of the application and drying periods required to sustain the infiltration rates of spreading basins. This application scheduling determines the hydraulic loading of the basin and hence the land area required for the system. In essence, the better the quality of wastewater in terms of suspended solids and organic matter, the smaller the area required for infiltration-percolation. This statement must be qualified, because it has been found that a certain amount of organic material has a beneficial effect on the infiltration capacity of a soil by acting as a granulating agent in soils during drying [65].

The degree of pretreatment required for an infiltration-percolation system to maintain infiltration capacity depends on the primary objective of the system. If the objective is to maximize the hydraulic acceptance of the system so as to minimize the land area required for spreading, then a high degree of pretreatment (secondary treatment or better) is justified. On the other hand, if the objective of the system is to use the soil matrix as a treatment system, then a lesser degree of pretreatment may be justified if proven operationally feasible by in situ pilot studies.

Primary sedimentation should be considered the minimum form of pretreatment to avoid operating and nuisance problems associated with coarse sewage solids. The feasibility of using primary effluent for infiltration-percolation has been demonstrated in the laboratory [26] and in the field [40]. Use of primary effluent will create a higher risk of operating problems due to severe clogging, especially at low temperatures [26]. The major long term impact of primary effluent will be to shorten the useful life of a system because of more rapid accumulation of nondegradable material in the soil.

It has been suggested that secondary biological treatment be the minimum degree of pretreatment for municipal infiltration-percolation systems to avoid the risk of frequent clogging [133]. Secondary effluent in this case refers to effluents with BOD and suspended solids concentration in the range from 10 to 30 mg/L [133]. All high rate systems in the United States reported in the literature provide a secondary treatment prior to spreading [6, 69, 77, 100, 119]. For the many moderate rate systems, primary, intermediate, and secondary effluents have been used successfully.

The presence of algae in applied wastewater has contributed to soil clogging problems at the groundwater recharge site in Hemet, California [119]. Researchers have found that algal growth in holding ponds has resulted in a tenfold increase in suspended solids concentration in secondary effluent to be applied to spreading basins. The algal solids hastened clogging and forced adoption of a longer drying cycle. This experience indicates that pretreatment to control algae growth may be necessary for systems with conditions that are conducive to algae growth.

The degree of pretreatment required to protect the groundwater quality depends on (1) the characteristics of the wastewater, (2) the renovative efficiency of the soil system, and (3) the beneficial use intended for the renovated water.

It has been well established that natural soil systems suitable for infiltration-percolation are highly efficient biological filters that are capable of almost complete removal of organic material, suspended solids, enteric bacteria, and viruses within the first few feet of percolation [3, 10, 15, 40, 41, 104]. These constituents are therefore not of general concern with respect to groundwater quality protection provided that the infiltration-percolation system is properly operated.

Other wastewater constituents which could affect groundwater quality include phosphorus, metals, boron, nitrogen, and dissolved solids. Because of the nature of the removal processes, soil systems have a finite capacity to remove phosphorus and constituents such as metals which depend on adsorption as the primary removal mechanism. In many cases, however, this capacity is quite large. If the presence of phosphorus in the final renovated water is undesirable for the beneficial use intended, as in the case of recreational lakes, then pretreatment to remove phosphorus may be required if the removal efficiency of the soil system is inadequate or the retention capacity is reached.

The heavy metals are present in municipal wastewaters in trace amounts. These metals are removed from solution by the adsorptive process and by precipitation and ion exchange in the soil. Accumulation of metals in the soil due to adsorption presents the risk of metal toxicity to plants and microorganisms in the soil. At present it is not economical to remove trace quantities of metals in conventional treatment plants. Therefore, in soil systems, as in receiving waters, the presence of some of the trace metals will be of concern. It has been suggested that it might be possible to restore the metal removal capacity of a saturated soil system by lowering the pH of the soil, leaching out the retained metals, and collecting and treating the leachate [133].

It is apparent that further research is required on the effects of inorganic materials on the operating life of a soil system and on restorative measures to offset these effects.

Boron is removed in the soil matrix by adsorption on soil particles containing aluminum oxides and iron. These materials are essentially absent in sandy soils that are suitable for infiltration-percolation; therefore, boron is generally passed on to the groundwater. If the recharged groundwater is to be used for irrigation, the concentration of boron is of concern. This concentration in municipal wastewater may increase in the future because of increased use of detergents containing borax or perborate [100]. However, boron is not expected to restrict the use of infiltration-percolation, except in areas having a high concentration of natural boron in the muncipal water supply which is then transferred to the wastewater. Pretreatment to remove boron alone is not considered economically feasible.

Nitrogen contained in municipal wastewaters applied to infiltration-percolation sites may take any of the pathways described in Section III under the nitrogen cycle. In contrast to irrigation systems, however, uptake of nitrogen by plants is not a significant removal mechanism for infiltration-percolation systems, even those with vegetated spreading basins. This is due to the relatively high volume of wastewater applied per unit of soil for these systems [56]. In addition, the lower clay and organic content of soils suitable for infiltration-percolation results in lower fixation capacity for ammonium ions. These conditions can lead to a significant loss of nitrogen to the groundwater as nitrate which can contaminate groundwater used for potable water supply or accelerate eutrophication in lakes and streams receiving recharged water. The presence of nitrates in groundwater used exclusively for crop irrigation is of less concern because plant uptake will remove significant quantities of nitrogen.

The loss of nitrates to the groundwater may be reduced either by pretreatment or by operating techniques which promote nitrogen removal by the other soil removal mechanisms. These operating techniques are discussed later in this section. In-plant pretreatment methods to remove nitrogen prior to land application include biological nitrification-denitrification, break point chlorination, ammonia stripping, and selective ion exchange. Another technique which can be considered pretreatment is dilution of the wastewater with low nitrate water prior to spreading. This form of pretreatment is successfully practiced at the Whittier Narrows, California, recharge site [69]. Dilution of recharged water by blending with in situ groundwater has been suggested as a means of mitigating the effects of high concentrations of nitrate in the percolate [69]. Blending of groundwaters, however, is a slow process requiring long detention times and long distances of horizontal travel by the recharged water. The feasibility of this practice therefore depends on the characteristics of the aquifer in the vicinity of the recharge area. If blending of natural and recharged groundwater is to be allowed, the natural groundwater should be receiving adequate additional replenishment with low nitrate waters to avoid a long term accumulation of nitrates.

It has been suggested that wastewater should be treated to convert all nitrogen to nitrate prior to infiltration-percolation to avoid adverse effects associated with nitrification in the soil [50]. The possible effects include: (1) reduction in the BOD removal efficiency of the soil and reduction in the length of time aerobic conditions can be maintained in the soil due to the high oxygen demand of the nitrification process [69]; (2) increased mineralization of groundwaters due to release of hydrogen ions during nitrification and subsequent dissolving of calcerous rock [50]; and (3) limitation of nitrogen removal by biological denitrification in the soil [133]. These effects, however, have not been specifically documented by field experience.

Further research to provide such documentation is warranted to provide a basis for determining pretreatment requirements. In fact, the coupling of the theory of environmental responses of the soil matrix, such as the nitrogen cycle, to practical field experience is generally lacking at this point. Research in this area is needed to optimize the application of in-plant treatment in conjunction with land application systems, especially infiltration-percolation systems.

Liquid Loading Rates – Infiltration-percolation systems have liquid loadings ranging from 18 to 500 ft/yr or, on a weekly basis, 0.3 to 10 ft/wk. Two of the most publicized sites, Whittier Narrows, California, and Flushing Meadows, Arizona, have operated at liquid loading rates as high as 10 ft/wk and 8 ft/wk, respectively [69, 100].

The design rate must be determined on the basis of pilot work. The percolation rate determined from this work should be used for loading rate design provided that it is not significantly greater than the infiltration rate. During actual operation the infiltration rate may become limiting because of clogging; however, with proper management the initial rates can be restored.

In the course of operation the liquid loading rate will undoubtedly change in response to climate, wastewater characteristics, or groundwater levels. The rates may also be modified in an attempt to improve the renovation in terms of nitrogen or phosphorus.

Organic Loading Rates – Organic loading rates depend upon the wastewater characteristics, the treatment system objectives, and the liquid loading rates. Suggested loading rates reported in the literature range from 7,400 lb/acre/yr for silt loam soil to 60,000 lb/acre/yr for sandy soil [123]. These loadings are based on the 5-day BOD. Actual BOD loadings in pounds per acre per year for operating systems are listed in Table 15. It should be noted that although the liquid loading rates in Table 15 are on the order of 50 to 100 times as large as those for irrigation sites, the organic loading rates are only about 5 times as large.

The BOD_5 should not be the only criterion in organic loadings. Total oxygen demand must also be considered. In the case of Whittier Narrows, subsurface anaerobic conditions have developed as a result of the nitrification of about 20 mg/L of ammonia nitrogen and long term carbonaceous oxygen demand. Although the effluent BOD_5 was about 5 mg/L,

Table 15. Existing Organic and Liquid Loading Rates for Infiltration-Percolation

Location	Organic loading, lb/acre/yr	Liquid loading, ft/yr	Reference
Hyperion, California	34,000	365	58
Santee, California	21,000	270	77
Flushing Meadows, Arizona	10,900	400	100
Westby, Wisconsin	9,700	36	--
Whittier Narrows, California	7,100	520	69
Lake George, New York	6,800	65	--

the ultimate oxygen demand, including that from nitrification, was about 150 mg/L [69].

Type of Basin Surface - The surface of an infiltration-percolation basin should be designed to disperse the clogging material applied [65]. The two principal methods of accomplishing this dispersion are: (1) growing vegetation on infiltrative surfaces, thus providing root channels with attendant soil expansion, and (2) covering surfaces with graded sand or gravel, thus encouraging clogging action in a matrix having larger pore spaces than the soil. On the basis of the literature there is no general agreement on the best type of basin surface. What has proved successful at one location has worked poorly at others. Selection of the type of basin surface should be based on comparative pilot studies at the infiltration site. Consideration should be given to renovative capacity and maintenance required in addition to infiltration capacity. The relative merits of the two types of basin surface are presented in the following discussion.

The effect of vegetated surfaces is illustrated at Flushing Meadows. In 1969 a comparison of the six basins was performed. Four were vegetated, one was left bare, and one was covered with gravel. The infiltration rate for the vegetated basins was 25 percent greater than those for the bare basin, and the bare basin showed greater infiltration rates than the gravel covered one [16, 134].

The advantages of vegetation include: (1) protection of soil from the impact of water droplets in areas of high rainfall, (2) additional nutrient removal if the vegetation is harvested (usually less than 5 percent) and (3) possible promotion of denitrification. Further research is required to substantiate the thesis that increased soil carbon around roots promotes increased denitrification.

The disadvantages of vegetation include increased maintenance and lower recharge depths. Loading cycles must be adjusted to promote plant growth in the early growing season and to permit harvesting. At Flushing Meadows the water depth, which was found to be directly proportional to infiltration rates, was restricted to avoid complete submergence. Giant bermuda grass proved to be the most suitable vegetation although rice and sudan grass were also tried [100].

The effect of nonvegetated surfaces is illustrated at the Whittier Narrows test basin, where 6 inches of pea gravel was spread over the bare soil to eliminate plant growth and decrease maintenance [69]. It was concluded that this layer was a major contributing factor to higher infiltration rates. On the other hand, studies with gravel layers at the Hemet and the Flushing Meadows recharge sites indicated that a gravel cover was not particularly effective in maintaining infiltration capacity [100, 119]. Researchers at Flushing Meadows hypothesized that the negative effect of the gravel layer on infiltration was due to a mulching action of the gravel layer and resulting poor drying of the underlying soil.

When using a gravel cover it has been suggested that abrupt changes in particle size should be avoided between the surface cover material and the soil at the infiltrative surface [65]. This precaution will prevent loss of infiltrative surface area as a result of blinding by large particles and will promote dispersion of clogging solids.

Distribution System - The distribution system consists of facilities to transfer wastewater to the site, outlet facilities, and hydraulic controls.

The transmission to the site can be by gravity or by pumping. For some of the intermittent dosage systems, the equivalent of 1 foot of water is applied in 30 minutes. The flow rate would be about 5,000 gpm for an area of 0.5 acre [131]. For long application periods, such as those at Flushing Meadows, the application is by gravity. Most sites simply have a single pipe from the source of wastewater to the site. Measurement is by flowmeter for pumped systems or by flume for gravity systems.

The outlet facilities usually consist of a single riser pipe in each basin. At Detroit Lakes, Minnesota, the application is by sprinklers [57]. Since most sites use the flooding technique, however, no special equipment is needed. Where velocities in one pipe are too high, a diffuser system of two or three outlets can be used. The lower the water velocity, the less erosion will occur at the outlet. A concrete splash pad is recommended at the outlet to distribute the flow.

The hydraulic controls of an infiltration-percolation system are not as sophisticated as for an irrigation system because the higher hydraulic loading rates do not require the fine control of an irrigation system. The infiltration rates are higher and there is little concern for ponding or vegetation damage. Since most sites are visited on a daily basis, the operation of two valves or slide gates per day requires minimum effort.

Provisions for Seasonal Changes - The uncertainty of weather patterns may require a factor of safety in the amount of land used or storage required. The climate will influence the operation of the site, especially where freezing temperatures are encountered for long periods of time. At Lake George, New York, the drying period is doubled in the winter to allow for the slower percolation rate. At this site, the winter flow is about one-quarter of the summer flow so the need for additional area does not occur.

At Hemet, California, three additional beds were constructed for use when other beds are out of operation because of maintenance requirements or emergency situations. The extra beds add 43 percent more area to the system [113].

The abnormal rainfall at Westby, Wisconsin, during the winter of 1972-1973 has created problems with the infiltration-percolation system. The extra water has taxed the system to the limit, and the operation has had to be altered to cope with the extra water. With little storage and no extra beds for emergencies, the ridge and furrow system has evolved into a series of holding ponds.

For design purposes, a certain percentage of the design area should be allotted for emergency situations. A reasonable range for general use would be 10 to 25 percent with 20 percent as typical. This will depend on conditions such as weather, available land, and the hazard involved should emergencies occur.

Recovery of Renovated Water - Recovery of renovated water is being carried out at a number of sites. At Whittier Narrows, the renovated water is pumped from the groundwater by individual wells. At Flushing Meadows, it is planned that the renovated water will be pumped to an irrigation canal for unrestricted reuse [134]. At Santee, California, the renovated water fills a series of four ponds that are used for recreational purposes. Swimming, boating, and fishing are some of the activities that take place on the lakes [77].

Recovery of renovated water can be an integral part of the system design, as at Flushing Meadows and Santee [77, 100], or it can be incidental with the normal withdrawal from the groundwater basin as at Whittier Narrows and Hemet [69, 119].

Designed recovery systems can prevent the spread of renovated wastewater to aquifers outside the system of recharge basins and recovery wells. By keeping the renovated wastewater separated from the natural groundwaters, contamination can be prevented, especially with regard to nitrates. In addition, renovated water recovered in this manner could receive additional treatment or could be used exclusively for purposes best suited to its quality, such as irrigation or recreational lakes. Design of this type of recovery system, however, requires a detailed knowledge of the subsurface geologic conditions and aquifer characteristics. A sufficient detention time and distance of underground travel must be allowed the percolated wastewater to permit renovation to be complete.

MANAGEMENT AND OPERATION

Important aspects of infiltration-percolation system management include (1) hydraulic loading cycles, (2) basin surface management, (3) operational problems, (4) monitoring, and (5) treatment efficiency.

Hydraulic Loading Cycles

It has been established that a schedule of intermittent application of wastewater is required to maintain reasonable infiltration rates and renovative capacities. At Hyperion and Flushing Meadows, continuous applications have been attempted which showed a constant drop in infiltration rates and a reduction of renovative capacity.

Optimum loading cycles will depend on the primary objective of the system. For instance, an application cycle which maximizes infiltration rates may minimize nitrogen removal by denitrification. It is therefore impossible to predict the optimum loading cycle for any one system [65]. The variation in reported loading cycles for existing systems, as shown in Table 16, illustrates this point. Experimentation is required to determine the best loading cycles consistent with the objectives of the system.

The resting period, which may vary from 1 to 20 days, is essential to allow atmospheric oxygen to penetrate the soil and reestablish aerobic conditions. As the surface dries, aerobic bacteria become active in organic matter decomposition and nitrification. This activity helps break up the clogging layer and free ammonium adsorption sites on clay and humus materials. In addition, prevention of severe anaerobic conditions through intermittent loading will avoid the possibility of leaching degradable organics into the groundwater.

Application frequency may affect the renovation that results from adsorption, by changing the detention time of the wastewater constituents in the soil matrix. The longer the detention time, the higher the probability of contact between wastewater constituent and adsorption site and the greater the overall renovation. Resting periods may also allow adsorbed ions to diffuse into interstices of the adsorbent particles which frees the external adsorption site. Further research is required to determine, in actual field operation, the relationship between adsorption effectiveness and application frequency.

Basin Surface Management

Where bare soil or gravel surfaces are used, they should be scarified or raked when solids accumulate. The frequency will depend upon the quality of the wastewater. More frequent raking is needed when water with high solids content is used. Operational experience will indicate the frequency; a typical frequency is once a year. The methods used have included shaving or sweeping [100], and disking, scarifying, and rototilling [119].

For vegetated surfaces the need is for careful operation of the loading cycle in the spring until the vegetation is

Table 16. Existing Hydraulic Loading Cycles

Location	Loading objective	Application period	Resting period	Reference
Flushing Meadows, Arizona				
Maximum infiltration	Increase ammonium adsorption capacity	2 days	5 days	100
Summer	Maximize nitrogen removal	2 wk	10 days	100
Winter	Maximize nitrogen removal	2 wk	20 days	100
Hyperion, California	Maximize infiltration rates	Continuous[a] 0.5 hr	-- 23.5 hr	58 131
Lake George, New York				
Summer	Maximize infiltration rates	9 hr	4-5 days	--
Winter	Maximize infiltration rates	9 hr	5-10 days	6
Tel Aviv, Israel	Maximize renovation	5-6 days	10-12 days	3
Vineland, New Jersey	Maximize infiltration rates	1-2 days	7-10 days	--
Westby, Wisconsin	Maximize infiltration rates	2 wk	2 wk	10
Whittier Narrows, California	Maximize infiltration rates	9 hr	15 hr	69

a. Abandoned after 6 months.

well established. The surface may be harrowed on an annual basis to break up any solids buildup.

Operational Problems

Problems developed with infiltration-percolation systems are generally related to the weather, mechanical breakdowns, or wastewater characteristics. At Hemet and Westby, severe prolonged rains have caused serious problems. At Hemet the solution was temporary abandonment of the system, while at Westby the rain and an overloaded plant may lead to permanent abandonment. At Lake George the snow and ice do not present serious problems. As the basins are flooded with effluent the ice is merely floated up 7 to 8 inches and serves to insulate the soil surface from further lowering of the temperature.

Mechanical breakdowns can be minimized by preventive maintenance; however, standby pumps and excess spreading basins are advisable.

At nearly all operating sites, problems relating to wastewater characteristics, primarily clogging, have occurred when abnormally high solids content water is applied to the land. At Whittier Narrows, the basin was taken out of service until the plant effluent quality was stabilized. At Flushing Meadows, the upper portions of the spreading basins were converted to settling basins to reduce the suspended solids content [15].

Monitoring

Monitoring is needed to maintain successful operation and to avoid conditions leading to significant environmental degradation. Flow meters or measuring flumes are necessary to measure the wastewater application rate. Infiltration rates will vary throughout the application period. For example, at Flushing Meadows the infiltration rate decreases linearly with time from 2.5 ft/day to 1.5 ft/day over the inundation period of 10 days. Should the infiltration rate, as monitored by flow recorders and/or level recorders, decline more rapidly than usual or fail to attain its original value after resting, measures must be taken to remedy the situation.

Sampling of the wastewater applied should be done on a regular basis for characteristics such as BOD, suspended solids, nitrogen, phosphorus, TDS, and coliforms. A complete analysis of minerals, including heavy metals, should be performed at a less frequent interval.

Groundwater or percolate water quality should be sampled for the same types of characteristics. The percolate water sampling arrangement used at Whittier Narrows is shown on Figure 8. For larger systems, sampling lysimeters have been used [90]. A modified lysimeter called a suction probe, which has been used by the Agricultural Extension Service in California, is illustrated on Figure 9.

Sampling and recording wells should be established around the spreading basin on the basis of the site selection geological data. Samples should also be taken from pumped recovery wells to determine final removal efficiencies.

Treatment Efficiency

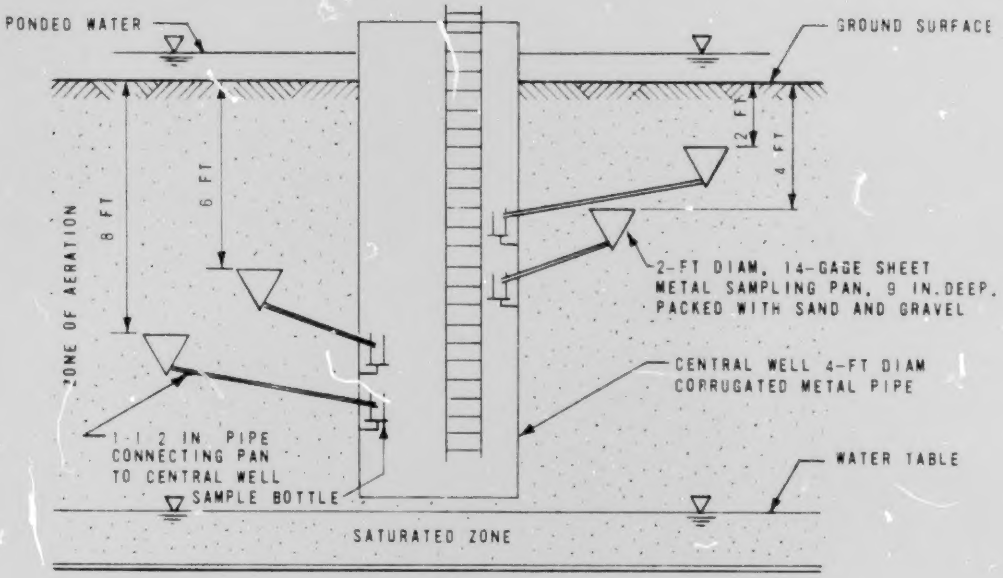
Removal efficiencies for infiltration-percolation systems are not as high as for irrigation systems because of higher loading rates, coarser textured soils, and lower clay content of soils. Removal of some constituents, such as suspended solids and bacteria, will be quite comparable to that of irrigation systems. Removal efficiencies at selected sites are listed on Table 17.

Removals of BOD are high but not as high as removals of suspended solids. The lower percentage removals of BOD for infiltration-percolation as compared to irrigation also reflect the higher quality of effluent applied to the land. For example, the effluent at Whittier Narrows averaged 5 mg/L of BOD. Other organics, such as detergents, are reduced by 90 percent [69].

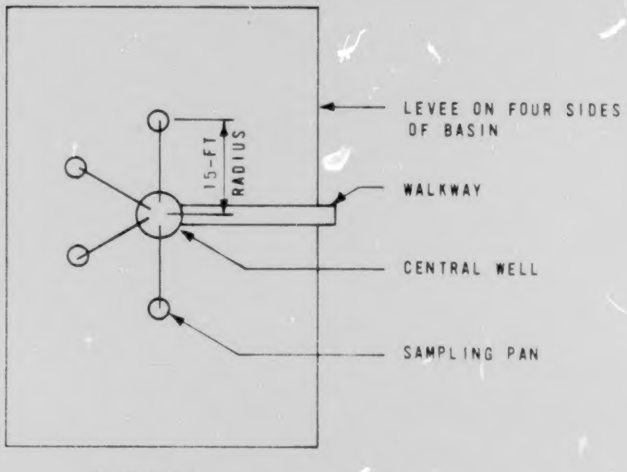
At Flushing Meadows nitrogen removals were as high as 80 percent after the high nitrate peak was flushed into the groundwater. This high removal is mainly the result of biological denitrification. At Whittier Narrows, however, the short frequent loading leads to excellent nitrification but essentially no denitrification and therefore no nitrogen removal.

Because infiltration-percolation system soils are not fine textured, there is less opportunity for removal of phosphorus and metals by adsorption. Nevertheless, phosphorus retention in sandy soils is significant. Only at Lake George, New York, where the system has been operating for 37 years, are there signs of phosphorus saturation of part of the available soil volume [6].

Generally, enteric coliforms and viruses are almost completely removed [16, 41, 77, 100]. The major exception is at Whittier Narrows, where coliforms tend to regrow in the soil. Extensive testing has shown sizable


PONDED WATER
GROUND SURFACE
ZONE OF AERATION
8 FT
6 FT
2 FT
4 FT
2-FT DIAM, 14-GAGE SHEET METAL SAMPLING PAN, 9 IN. DEEP, PACKED WITH SAND AND GRAVEL
CENTRAL WELL 4-FT DIAM CORRUGATED METAL PIPE
1-1 2 IN. PIPE CONNECTING PAN TO CENTRAL WELL
SAMPLE BOTTLE
WATER TABLE
SATURATED ZONE

SCHEMATIC CROSS SECTION


LEVEE ON FOUR SIDES OF BASIN
15-FT RADIUS
WALKWAY
CENTRAL WELL
SAMPLING PAN

PLAN VIEW

FIGURE 8
SCHEMATIC OF SAMPLING PAN WELL
AT WHITTIER NARROWS, CALIFORNIA [69]

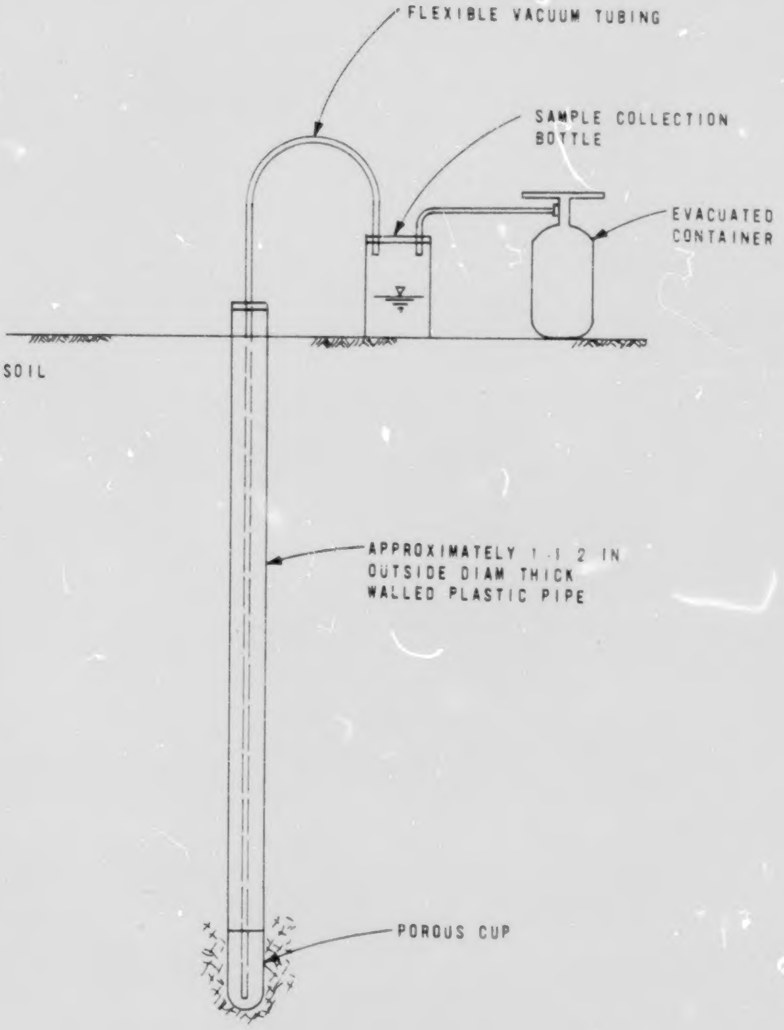

FLEXIBLE VACUUM TUBING
SAMPLE COLLECTION BOTTLE
EVACUATED CONTAINER
SOIL
APPROXIMATELY 1-1 2 IN OUTSIDE DIAM THICK WALLED PLASTIC PIPE
POROUS CUP

FIGURE 9
SUCTION PROBE FOR SOIL WATER SAMPLING

Table 17. Removal Efficiency at Selected Infiltration-Percolation Sites

Location	Depth sampled, ft	Removal efficiency, %					Reference
		BOD	SS	N	P	E. Coli	
Flushing Meadows, Arizona	30	98	100	30-80	60-70	100	15
Hyperion, California	7	90	--	--	--	98	58
Lake George, New York	10	96	100	43-51	8-61	99.3	6
Santee, California	200[a]	88	--	50	93	99	77
Westby, Wisconsin	3	88	--	70	93	--	10
Whittier Narrows, California	8	--	--	0[b]	96	0[c]	69

a. Lateral flow.

b. Short frequent loading promotes nitrification but not denitrification.

c. Coliforms regrow in the soil.

concentrations of coliforms at the 8-foot depth, but an almost complete absence of fecal coliforms [69]. Virus testing at Whittier Narrows in February 1963 showed 250 units of enteric virus per liter in the effluent, but no measurable concentration in the percolate at the 2-foot depth. More extensive tests at Santee have yielded the same results [77].

ENVIRONMENTAL EFFECTS

The main effects of infiltration-percolation systems are on the groundwater, soil, and vegetation. The effects on air, surface water, and wildlife are generally negligible.

Groundwater

Groundwater is affected in terms of quantity and quality. Groundwater recharge must either reverse or slow the drop in the groundwater levels, or it must repel the intrusion of salt water into fresh water aquifers. The latter is the case at Hemet and Whittier Narrows, California, where the intruding sea water has been repelled by recharge. At Whittier Narrows and the nearby Rio Hondo spreading basins, Colorado River water and storm water have been spread along with secondary effluent.

The effects on groundwater quality are mainly due to nitrogen, phosphorus, organics, toxic elements, and TDS. The movement and effects of pathogens in groundwater will be discussed under "Public Health Considerations."

Nitrogen – Nitrogen in the form of nitrates is passed into the groundwater in significant quantities at nearly every infiltration-percolation site. The only systems where significant removals occur are Flushing Meadows and Westby, Wisconsin. Both operated with long flooding and drying periods which promoted denitrification. The effects of nitrates on eutrophication and public health have been discussed in Section IV.

Phosphorus – Because of the use of granular soils, the removal of phosphorus may be limited. Phosphorus reaching the groundwater may be a problem if the recovered water is used in recreational lakes such as at Santee, or if the recharged water reaches a surface body of water such as at Lake George. The problem is the increased eutrophication of the water bodies.

Organics – If organic matter, particularly refractory organic matter, reaches the groundwater, it may pose a health hazard when the water is recovered for reuse. At present existing installations there is evidence that little organic matter reaches the groundwater [69,100]. The effects of refractory organics in groundwater is a subject currently requiring further research. Degradable organics can also impart taste and odor to groundwater and deplete the dissolved oxygen.

Trace Elements – Trace element retention in soils of infiltration-percolation may be limited because of the granular nature of the soil. The buildup of organic humus in the soil will tend to offset this deficiency, however, and long term retention may occur. After passage through 30 feet of soil at Flushing Meadows, the renovated water contained 2 to 2.5 mg/L of fluoride, 0.2 mg/L copper, 0.1 mg/L zinc, 0.07 mg/L lead, and 0.007 mg/L cadmium [15]. These concentrations represent only slight reductions (about 10 percent), in most cases, from the concentrations in the applied effluent.

Total Dissolved Solids – The public health aspects of TDS buildup have been discussed in Section IV. Although rapid infiltration of wastewater minimizes salinity increases due to evaporation losses, the continuous recycle of water through consumptive use, recharge, and reuse, will lead to an increase in TDS. In relatively small, closed hydrologic basins this will occur more rapidly than in unconfined basins. For example, at Santee, California, where annual evaporation is far greater than rainfall, it may be necessary to demineralize a portion of the water as it passes through the reuse cycle.

Soil and Vegetation

The effects of land application of wastewater on soil and vegetation have been detailed in Section IV. The major effect of infiltration-percolation on vegetation which differs from the effects already discussed, is that of overwatering. At Westby, Wisconsin, the Reed canary grass planted in 1971 and 1972 did not grow because excess wastewater had to be applied to the basins. At Detroit Lakes, Minnesota, as mentioned previously, and at Seabrook Farms (see Section VI), the native trees were killed by the heavy applications of water [57].

PUBLIC HEALTH CONSIDERATIONS

State regulations may have an effect on infiltration-percolation systems. Other public health considerations involve the movement of bacteria and viruses, movement of toxic compounds, and insect and rodent problems.

State Regulations

Regulations concerning infiltration-percolation systems deal mainly with control of groundwater quality. Proof, in the form of monitoring data, that the groundwater is not being polluted is often required. At Vineland, New Jersey, primary effluent is applied to sandy soil without underdrains, and no monitoring of groundwater quality is practiced. To meet new state and federal regulations, secondary treatment is being designated prior to land application. The Landis Sewerage Authority (Vineland) has resolved to reduce organic and nitrogen loadings so that groundwater withdrawn 500 feet away in any direction from the site will meet New Jersey potable water standards. Pretreatment of industrial-commercial wastes will be required by the Authority to eliminate all toxic substances and reduce nitrate nitrogen to a maximum of 10 mg/L.

Although practical considerations, such as clogging, necessitate pretreatment at least to primary effluent, few regulations require pretreatment levels. At Nantucket, Massachusetts, as discovered in the APWA survey, infiltration-percolation is practiced with untreated wastewater.

Movement of Bacteria and Viruses

The spread of pathogens is of concern because of the possibility of disease transmission. Bacteria and viruses can be spread by insects or by the percolating water. At Flushing Meadows, mosquitoes are not a problem despite the 20-day inundation period.

The movement of bacteria and viruses with the percolating water is not likely to cause a threat to health. Numerous studies at existing sites and in laboratory experiments indicate that most bacteria and viruses are removed after passage through a few feet of soil [15, 28, 33, 41, 53, 54, 55, 69, 138]. At Santee, California, viruses injected into the percolating water were completely removed in 200 feet of horizontal and vertical travel [77].

Movement of Toxic Compounds

Toxic compounds are generally more difficult to remove by infiltration-percolation than are bacteria. Studies have indicated that chemicals travel 2 to 30 times as far through soil as bacteria [104]. Examples of both chemical and bacterial travel through soil and groundwater are listed in Table 18. Where known toxicants are present in wastewater applied to the land, an intensive monitoring and control program should be maintained to preclude contamination of the groundwater.

SYSTEM FAILURES

An infiltration-percolation site can be abandoned for any number of reasons, ranging from public complaints to degradation of the groundwater supply. The reasons that are discussed here are overloading and groundwater degradation.

Limits of Loading

Systems can be overloaded by liquids, organics, or nutrients. Any of these forms can saturate a soil and sharply reduce its usefulness as a treatment and disposal medium.

Liquid Loading – When a soil becomes saturated with wastewater, anaerobic conditions will soon prevail, and the soil will become sealed. Without an adequate drying period, aerobic conditions will not return and the system will fail.

Table 18. Summary of Distances of Travel of Pollution in Soil and Groundwater [104]

Nature of pollution	Pollutant	Observed distance of travel[a]	Time of travel
Sewage polluted trenches intersecting groundwater	Coliform bacteria	65 ft	27 wk
	Chemicals	115 ft	--
Polluted trenches intersecting groundwater	Coliform bacteria	232 ft	--
	Uranin	450 ft	--
River water in abandoned wells	Intest. pathogens	800 ft	17 hr
	Tracer salts	800 ft	17 hr
Sewage in bored latrines intersecting groundwater	Coliform bacteria	10 ft	
	Anaerobic bacteria	50 ft	
	Chemicals	300 ft	
Sewage in bored latrines lined with fine soil	Coliform bacteria	10 ft	
Sewage in bored latrines intersecting groundwater	Coliform bacteria	35 ft	
	Chemicals	90 ft	
Sewage in bored latrines intersecting groundwater	Coliform bacteria	80 ft; regressed to 20 ft	
Coliform organisms introduced into soil	Coliform bacteria	50 m	37 days
Sewage effluents on percolation beds	Coliform bacteria	400 ft	
	Ammonia	1,400 ft	
Sewage effluents on percolation beds	Bacteria	150 ft	
Sewage polluted groundwater	Bacteria	a few meters	
Introduced bacteria	*Bacillus prodigiosus*	69 ft	9 days
Chlorinated sewage	Phenols, fungi	300 ft	
	Dye	300 ft	24 hr
Industrial wastes	Tar residues	197 ft	
	Picric acid	several miles	
Industrial wastes	Picric acid	3 mi	4.5 yr
Industrial wastes in cooling ponds	Mn, Fe, hardness	2,000 ft	
Chemical wastes	Miscellaneous chemicals	3-5 mi	
Industrial wastes	Chromate	1,000 ft	3 yr
	Phenol	1,800 ft	
	Phenol	150 ft	
Weed killer wastes	Chemical	20 mi	6 mo

a. For bacteria, the distance observed was the extent of travel; for some chemicals the observations were taken along paths of unknown extent.

An example is Westby, Wisconsin, where the infiltration beds have become holding ponds.

Organic Loading – As stated in the previous section, the organic loading limit of 30 tons/acre/yr will not usually be reached except in the disposal of sludge. At Marysville, California, the percolation ponds were plugging too rapidly, so the pretreatment was increased from primary to secondary. This is a case of management recognizing an overloading condition and taking necessary corrective action.

Nutrient Loading. – There are no known systems that have failed solely because of nitrogen. The South Lake Tahoe system was removing only 50 percent of the influent nitrogen which contributed to its abandonment [36]. Systems such as Whittier Narrows have not been abandoned despite the fact that the nitrogen applied is not removed, merely changed to the nitrate form.

Infiltration-percolation systems tend to have limited exchange capacities for removal of phosphorus. At Lake George, New York, some percolation beds appear to be saturated with phosphorus because little renovation is occurring at the 10-foot depth [6].

Groundwater Degradation

Groundwater degradation is closely tied to overloading and mismanagement. Extensive monitoring and control practices should be maintained to forecast and prevent degradation from occurring. Because infiltration-percolation will certainly affect the groundwater to some extent, it is important to manage the groundwater and maintain control of its movement.

SECTION VI

LAND APPLICATION OF INDUSTRIAL WASTEWATER

BACKGROUND

Application of industrial wastewater to the land for treatment and disposal has been a relatively recent development in the history of land application of wastewaters. Reports of land application operations specifically for industrial wastes did not appear in the literature until the 1940s [61]. Since that time, however, there has been a dramatic increase in the number of industrial wastewater land application sites. A 1965 survey indicated that over one-third of all land application sites in the United States were serving the food processing industry alone [9].

Several factors are responsible for the increased interest. The principal driving force is the intensified effort to reduce pollutional loads on the nation's surface waters. Land application of wastewaters is a means by which discharge to surface waters can be eliminated, and it has also proven to be an economic alternative to conventional treatment methods at several sites where effluent is discharged. Most land treatment and disposal techniques avoid the problems of system startup associated with conventional treatment facilities used for seasonal industries.

Extensive use of land application has been restricted primarily to three industries--namely, the food processing industry, which accounts for the majority of applications; the pulp and paper industry; and the dairy industry. Two reasons for the development of land wastewater application in these industries are: (1) the location of process operations in rural areas with close access to suitable land, and (2) the nature of their wastewaters, which are generally nontoxic and easily biodegradable.

The methods of land application described earlier for municipal wastewater are applicable to industrial wastewaters; however, the systems must be designed and operated to account for the differences in wastewater characteristics. The purpose of this section is to discuss those considerations which must be given to the design and operation of land treatment and disposal systems receiving industrial wastewaters.

WASTEWATER QUALITY AND PRETREATMENT REQUIREMENTS

Consideration must first be given to the quality of the wastewater to be applied to the land. This requires a complete characterization of the wastewater with regard to constituents that may affect or interact with the soil or groundwater. The presence of constituents which may adversely and irreversibly affect the soil and groundwater environment can preclude the use of a land application system unless they can be economically removed from the wastewater prior to application. Pretreatment may also be required to remove constituents that impair the efficient operation of the system, but are not necessarily damaging to the terrain ecosystem.

Wastewater Characteristics

Industrial wastewaters contain many of the constituents found in municipal wastewaters as described in Section IV. The characteristics of industrial wastewaters vary widely not only by industry but also by product. Moreover, even when plants are similar, their wastewater characteristics may vary according to the processing technique used. Consequently, there is no such thing as a typical industrial wastewater unless the various processes generating the wastewater are well defined. There is no attempt in this report to typify the myriad industrial wastewaters. Rather, those wastewater constituents that should be considered in connection with land application systems are identified, and their potential impact is discussed. The more important constituents are listed in Table 19 along with ranges or upper limits of concentrations which have been successfully applied to the land as reported in the literature. This list is not intended to be exhaustive, but it illustrates the types of industrial wastewaters that are amenable to land application. Important characteristics are BOD and COD, suspended solids, total fixed dissolved solids, nitrogen, pH, temperature, color, heavy metals, and the SAR.

BOD and COD - The COD is a measure of the total organic content of a waste, while the BOD indicates what portion of those organics are biodegradable in a specified period of time. The ratio between COD and BOD is therefore a useful parameter in determining the degradability of a wastewater. Easily degradable wastewaters, such as those from the

Table 19. Characteristics of Various Industrial Wastewaters Applied to the Land

Constituent	Food processing	Pulp and paper	Dairy
BOD, mg/L	200-4,000	60-30,000	4,000
COD, mg/L	300-10,000	--	--
Suspended solids, mg/L	200-3,000	200-100,000	--
Total fixed dissolved solids, mg/L	1,800	2,000	1,500
Total nitrogen, mg/L	10-50	--	90-400
pH	4.0-12	6-11	5-7
Temperature, deg F	145	195	--

industries listed in Table 19, are well suited to land application because the soil mantle is a highly efficient biological treatment system. There are limits, of course, to the amount of degradable material that can be placed on the land without stressing the terrain ecosystem. Permissible organic loading rates will be discussed later in this section. Organics in the form of sugars are more readily degradable than starchy or fibrous material. Consequently, those wastewaters which contain predominantly sugars, such as food processing wastes, may be applied at a generally higher organic rate than wastewaters from the pulp and paper industry which often contain starchy or fibrous material. Industrial wastewaters containing significant concentrations of nondegradable or resistant organics in solution are generally not suitable for land application, because these materials can cause severe soil clogging. Also, they are likely to enter the groundwater and impart undesirable tastes and odors.

Suspended Solids — Suspended solids may include coarse solids, such as peelings and chips, or fine solids, such as silt and small organic particles. Cannery wastewaters often contain large amounts of silt which is washed off fruits and vegetables. The presence of high concentrations of solids in a wastewater does not restrict its application to a land treatment system because solids can normally be separated quite simply by pretreatment. Failure to provide adequate solids removal, however, can impair the operation of the system by clogging of the soil or sprinkler nozzles.

Total Fixed Dissolved Solids – The importance of the mineral content of a wastewater applied to the land has been discussed in detail in Sections IV and V. The major problem associated with dissolved solids is that the soil mantle does not provide mechanisms to remove them permanently from solution. Consequently, mineral salts either build up their concentration in the soil solution or are leached to the groundwater. Industrial wastewaters with very high total fixed dissolved solids are therefore not generally suitable for land application unless special provisions are made to collect soil drainage.

Nitrogen – The nitrogen content of many industrial wastewaters is usually of less concern than that in municipal wastewaters. The reason is that the carbon to nitrogen ratios found in most industrial wastewaters permit a larger portion of nitrogen to be removed by bacterial assimilation and incorporation into cellular material. Notable exceptions are feed-lot, dairy, and meat packing wastes. The latter have been found to contribute a significant nitrate load to groundwaters [50].

pH – The pH of industrial wastewaters varies over a wide range, even in the wastewater from one plant. This is especially true of cannery wastewaters that include washwater from lye peeling operations. Waters having a pH between 6.5 and 9.5 are generally suitable for application to most crops and soils [12]. Wastewaters with a pH below 6.5 have been successfully applied to soils that have a large buffering capacity. However, wastewaters having excessive acidity or hydroxide alkalinity must normally be neutralized to be suitable for land application.

Temperature – The high temperatures of some industrial wastewaters, such as spent cooking liquors from pulping operations, can sterilize the soil, thus precluding the growth of vegetation and reducing the renovative capacity of the soil mantle [43]. High temperature wastewaters should, therefore, be cooled prior to land application.

Color – The color in most industrial wastewaters is associated with degradable organic material and is effectively removed as the wastewater percolates through the soil mantle. However, some wastewaters--for example, spent sulfite liquor--contain colors associated with relatively inert components such as lignins. It has been observed that this color is not only transmitted through the soil but also intensified by the formation of organic complexes [12]. Groundwater contamination with this type of wastewater is difficult to avoid. This fact must be considered carefully when evaluating land application of such wastewaters.

Heavy Metals – Industrial wastewaters containing significant concentrations of heavy metals generally are not suitable for application to most soils. However, successful operations with such wastewaters have been reported. A paper processing plant in Vicksburg, Michigan, applies high concentrations of lead, vanadium, and cadmium to a peat-type soil. The high organic content of the soil provides a large heavy metal retention capacity, although this capacity is expected to be exhausted within 20 years. For such wastewaters the response of the soil at a proposed site to the wastewater to be applied should be studied carefully prior to full-scale operation.

Sodium Adsorption Ratio – It is preferable that the SAR (defined in Section III) of wastewaters applied to the land be less than 8 to prevent deflocculation of clay soils. This property is less critical with sandy soils. Industrial wastewaters with extremely high SAR's must be applied using special soil management procedures to compensate for the effect of the sodium. A pulping operation in Terre Haute, Indiana, applies 0.2-mgd sodium base cooking liquor containing 16.4 percent sodium (percent of dry solids) to a land disposal site, but once the soil structure is destroyed, the site must be rested for several years, and a source of calcium must be added to the soil to replace the sodium [43].

Pretreatment Requirements

In contrast to municipalities, industry has viewed land application more as an alternative to conventional treatment methods than as an advanced stage of treatment. Consequently, industrial systems rely more on the renovative capacity of the soil mantle, and pretreatment is generally minimized. Pretreatment is required in most cases to eliminate frequent operating difficulties and, in some cases, to avoid adverse effects on the terrain environment.

Screening – Screening with rotary or vibrating screens has been almost universally employed as a form of pretreatment to separate coarse solids from industrial wastewaters. Coarse solids can cause serious problems with distribution of the wastewater, particularly if spraying is used. Fine screens at pump inlets or in-line screens in the discharge piping may also be employed as an added precaution against spray nozzle clogging. Experimental work has been conducted on pea processing wastewater to determine the feasibility of comminuting solids and including them in wastewater applied to the land by sprinklers [20]. The study indicated that this approach did not adversely affect the soil or vegetation; however, insufficient disintegration of fibrous solids by comminutors resulted in sprinkler clogging problems. Use of this system on other types of wastewaters must be evaluated for the wastewater in question.

Lagooning - The use of lagoons or settling ponds prior to land application of industrial wastewaters has been prevalent. Such lagoons serve to remove silt and other suspended particles which may contribute to clogging of the distribution system as well as hasten the clogging of soil pore space. The BOD of the wastewater can be reduced substantially in lagoons depending on the detention times. Lagoons also serve to equalize wastewater flows and strength and thereby provide more flexibility to the operation of the system and prevent shockloading. Lagoons, however, are not without their problems. The generation of odors resulting from anaerobic conditions is the principal drawback reported in the literature. Odors reached objectionable levels at several systems that sprayed lagooned wastewater [27]. The odor problem was eliminated by bypassing the lagoon and spraying fresh wastewater. Odor control by the addition of sodium nitrate to eliminate anaerobic conditions is possible but not always practical because of dosage requirements. Additionally lagoons must be constantly maintained to prevent propagation of insects, and accumulated solids must be removed periodically.

At many industrial sites, lagoons were not designed as part of the land application system but were remnants of previous treatment facilities included in the new system. The decision to provide lagooning prior to land application should be based on considerations of odor production potential, desirability of equalization, the effect of solids on the application system, and economics.

pH Adjustment - Industrial wastewaters with sustained flows outside the pH range of 6 to 9.5 should be neutralized prior to land application if the site is to be vegetated. Wastewaters with widely fluctuating flows can be self-neutralizing if an equalization basin is provided prior to land application. In other cases a continuous pH control system may be necessary. This type of pH control may be accomplished in a pipeline or in neutralization basins.

The use of neutralization basins is normally preferred because less sophisticated equipment is required to obtain adequate control.

Cooling – For wastewaters below 150 deg F, application by sprinkling normally provides sufficient cooling to protect vegetation and soil. Such cooling may be enhanced by the use of sprinklers that produce small spray droplets or that have large spray diameters. Wastewaters with temperatures much above 150 deg F generally should be cooled prior to spraying if vegetation is desired.

TREATMENT BY OVERLAND FLOW

Treatment of wastewater by overland flow consists of the filtering action of vegetation as the wastewater flows over the sloped land surface. Bacteria present on the grass and vegetative litter act to decompose the solids and organics. The process has been well developed in this country for treatment of food processing wastewaters.

The overland flow method was developed to take advantage of the low permeability properties of heavy soils. The properties of clay soils are discussed under "Soil Characteristics" in Section IV. The technique was pioneered in this country at the Campbell Soup Company plant at Napoleon, Ohio, in 1954 [109]. It was discovered that runoff from spray application traveling down the relatively steep slopes was receiving a high degree of treatment. This principle of grass filtration has been refined through experience at several other overland flow or spray-runoff installations.

Overland flow differs from spray irrigation primarily in that a substantial portion of the wastewater applied is designed to run off and must be collected and discharged to receiving waters, or in certain cases where wastewater is produced only during part of the year, stored for deferred application. An overland flow system, therefore, functions more as a land treatment system than a land disposal system. The design and operation of overland flow systems are discussed in the following paragraphs.

System Design

The design of an overland flow system entails: (1) selection of a site with proper conditions of soil type, topography, and climate; (2) determination of the land area required to accept the wastewater; (3) selection of a suitable cover crop; and (4) layout of the distribution and collection system.

Site Conditions and Land Preparation - The most important criterion to be used in selecting a site for overland flow is the structure of the soil. Soils with minimal infiltration capacity, such as heavy clays or clay loams, are required for this technique to be effective. Soils with good drainage characteristics are better suited to irrigation or infiltration-percolation techniques.

A sloping terrain is necessary to allow the applied wastewater to flow slowly over the soil surface to the runoff collection system. The slopes must be steep enough to prevent ponding of the runoff, yet mild enough to prevent erosion and provide sufficient detention time for the wastewater on the slopes. Experimental work at Paris, Texas, has indicated that best results are obtained with slopes between 2 and 6 percent [24]. Slopes must be uniform in cross slope and free from gullies to prevent erosion and allow uniform flow over the slopes.

A slope length of 175 feet was found at Paris, Texas, to provide a sufficient detention time to achieve effective treatment of the wastewater. The wastewater at the Paris facilities is a highly degradable food processing wastewater with an average BOD concentration of 500 mg/L. Longer slopes may be necessary for higher strength or less easily degradable wastewaters or for colder climates. This would have to be evaluated for the individual wastewater and location.

The network of slopes and terraces that make up an overland flow system may be adapted to natural rolling terrain, as has been done at Napoleon, Ohio [9]. The use of this type of terrain will minimize land preparation costs. The overland flow system has been adapted to severely eroded land at Paris, Texas, and to relatively flat land at Davis, California, by substantially reshaping the terrain. Where such reshaping is required, the finished grading must be done to close tolerances to prevent erosion. Care must also be taken to reestablish topsoil on the constructed slopes to provide an adequate seed bed for the cover crop.

The system at Davis, California, consists of a series of slopes and terraces constructed in a sawtooth pattern [85]. Experience with this system indicates that an undular pattern of opposite facing slopes with collection ditches between would provide greater operating flexibility under changing wind conditions.

The overland flow system may be adapted to almost any climate, although a warm semiarid climate is preferable. There are no systems identified in this study that operate under prolonged freezing conditions. This is an area that requires further field research.

If it is not possible to reuse the runoff from the overland flow system, then a waterway or drainage system must be in the vicinity to transport the effluent from the site. Requirements set by state agencies for discharge into receiving waters are often quite stringent, and the treatment efficiency of the overland flow system must be sufficient to meet any such requirements.

Since infiltration into the soil is minimal in overland flow, the effects of the system on groundwater and, conversely, the effects of groundwater on the system are not as critical as with other application methods. The depth of groundwater below the soil surface is the point of major concern. This depth must be sufficient so as not to affect the growth of the cover crop. This condition is discussed in Section IV.

Loading Rates – The area of land selected for an overland flow system will set the overall loading rates on the system with regard to wastewater volume, organic material, solids, and nutrients. Loading rates differ from application rates or application frequency in that they refer to the long term average conditions for the entire site, while the others refer to short term operating conditions. Application rates and frequency are discussed under system operations.

Liquid loading rates are normally reported in units of gallons per acre per day or inches per day and are calculated by dividing the field area of the site by the average daily wastewater flow. The field area is the acreage of the terraced treatment system. The term "wetted" acres refers to the area covered by the spray diameters and is less than the "field" acres. The liquid loading rates used during peak production periods at existing overland flow facilities are listed in Table 20 along with the average daily flow rates. Loadings will vary with the production of wastewater at the processing plant. Those shown in Table 20 are for peak season conditions.

Organic and suspended solids loadings are also indicated in Table 20. These are based on the average BOD and suspended solids concentration of the applied wastewater. Although all of the systems to date have been designed using hydraulic loading as the primary sizing criterion, there has been no information reported correlating the BOD loading with treatment efficiency. For higher strength wastewaters

Table 20. Peak Season Loading Rates of Overland Flow Treatment Systems

Site location	Average flow, mgd	Field area, acres	Liquid loading rate, in./day	Organic loading rate, lb BOD/acre/day	Suspended solids loading rate, lb/acre/day
Napoleon, Ohio	4.0[a]	335	0.45	40	36
Paris, Texas	3.5[b]	385	0.35	37	18
Chestertown, Maryland	0.7[b]	70	0.4	67	29
Davis, California	3.25[c]	250	0.5	100	56

a. 10-month operating season.
b. Year-round operation.
c. 3-month operation season.

this parameter may well govern. This is an area where further research is necessary.

Nutrient loading rates were not used as a design parameter for the current systems. However, nutrients undoubtedly are important to the performance of a system, since overland flow is essentially a biological treatment system. Further study is therefore warranted to determine the effects of nutrient loading on system performance.

Cover Crop Selection – The cover crop is one of the essential components of an overland flow system. It acts to prevent soil erosion, provides removal of nutrients through uptake, and, most importantly, serves as media for the microbial population whose metabolic activity provides the wastewater treatment. The grass serves in a manner similar to rock or plastic media in a conventional trickling filter. Thus, overland flow has also been referred to as grass filtration. In addition, when the crop is harvested, it may be removed and sold for cattle feed.

Perennial grasses with long growing seasons, high moisture resistance (hydrophytic), and extensive root formation are best suited to the application. Comparative field studies at Paris, Texas, indicated that Reed canary grass was the superior grass at that location. It demonstrated a very high nutrient uptake capacity and yielded a high quality hay upon harvest [24]. Hauling the crop away during harvest provides positive removal of the nutrients taken up during plant growth. The amounts of nutrients taken up by crops are listed in Tables 5 and 11 in Section IV.

Tall fescue has also been used as a cover crop and, under laboratory conditions, was found to be superior to Reed canary grass [12]. However, the Paris field studies indicated that the semidormant behavior of tall fescue after harvest allowed the intrusion of undesirable native grasses.

Reed canary grass is a slow starting grass and therefore should be planted with a nurse crop, such as rye grass or tall fescue. The experience at Paris, Texas, with tall fescue indicates that rye grass would be a better selection. However, moderate irrigation of the system would be required until the Reed canary was established because the rye grass has a lower moisture resistance.

The suitability of Reed canary grass under various climatic conditions has yet to be established. The crop selection for the facility at Davis, California, was made with this in mind. A combination of Reed canary, fescue, trefoil, and Italian rye grass was planted. Reed canary has emerged but after 2 seasons has yet to become the dominant species. Further study is warranted to determine the best cover crop for the overland flow process under various climatic conditions. Other species, such as bermuda grass, may also be suitable.

Distribution and Collection System — Distribution of the wastewater in an overland flow system is accomplished by sprinklers. Spraying is necessary to distribute the organic and solids load over a wide area to avoid overstressing any one portion of the system. The discussion presented in Section IV on the design of sprinkler installations also applies to overland flow systems. However, there are some particular considerations which must be given to the design of an overland flow sprinkler system.

The principle of overland flow requires the wastewater to be distributed along the top of a slope and allowed to flow down to the collection system. Sprinklers are therefore placed so their spray diameter covers approximately the upper one-third to two-thirds of the slope. The sprinkler setting must allow for overlap to provide efficient area coverage. More overlap is necessary where high winds are expected. As an example, the system at Davis, California, was designed with a sprinkler spacing of 100 feet, a sprinkler discharge of 25 gpm at 60 psi, and a spray diameter of 130 feet. The sprinklers were placed 65 feet from the top of each slope.

Buried, permanently set sprinkler systems have been found preferable to portable aluminum systems. The major cost advantage in portable systems is lost when used for overland flow because the short cycle periods make hand moving of laterals impractical. In addition, experience at Paris, Texas, with portable systems has shown that leakage from high pressure portable mains can result in severe erosion of the slopes. Portable laterals also pose a barrier to the downslope runoff, which can adversely effect distribution and cause ponding on the slopes.

Individual sprinkler risers should be provided with isolating valves to allow malfunctioning sprinklers to be shut off under pressure. This provision will protect the slope from erosion caused by heavy streams of water which may occur during breakdown. Lateral lines should be provided with cleanouts to allow removal of solids that may build up in the line.

Automatic or centralized remote controls are recommended for systems to reduce the risk of human error and manpower requirements. Such controls have proven reliable and will generally result in lower operating costs. The pneumatic controls employed at existing installations have provided the systems with excellent operating flexibility.

A network of ditches must be constructed to intercept the runoff and channel it to the point of discharge or storage. The interception ditches are normally not lined. They must be graded to prevent erosion, yet, at the same time, they must have sufficient slope to prevent ponding in low spots. The collection system must be designed to accept the added flow from rainfall runoff. This is particularly important if the effluent is to be pumped.

For some summer seasonal operations it may be possible to store runoff from the system and reuse it in the following spring to meet the irrigation demands of the cover crop. Provision would have to be made for handling storm water runoff in excess of storage capacity.

Operation and Management

As with any land application process, conscientious management is critical for effective performance. Ideally a system should be operated by personnel with agricultural experience, although this is not essential. A well designed system should perform properly if it is not neglected. The major tasks involved in operating an overland flow system include (1) maintaining the proper application rate and application frequency or hydraulic loading cycle, (2) managing the soil and cover crop, and (3) monitoring the performance of the system.

Hydraulic Loading Cycle – Cycling of the wastewater application must be programmed to keep the microorganisms on the soil surface active. Once again, the principle is similar to a conventional trickling filter with intermittent dosing. The application period should be controlled so as not to overstress the system and bring about anaerobic conditions. The resting period should be long enough to allow the soil surface layer to reaerate, yet short enough to keep the microorganisms in an active state. Experience with existing systems indicates that optimum cycles range from 6 to 8 hours on and 6 to 18 hours off, depending on the time of the year. Application periods may be extended during the summer months to allow portions of the system to be taken out of service for crop harvesting. Application rates or discharge rates are normally held constant and are determined by the sprinkler selection. The rates on existing systems surveyed range from 0.05 in./hr to 0.1 in./hr, using sprinklers with a discharge of 15 to 30 gpm.

Cover Crop and Soil Management – Just as equipment in conventional treatment facilities must be maintained, the cover crop and soil in overland flow systems must receive attention in the form of soil amendments, fertilization, pest control, and harvesting. The most important of these tasks is harvesting. Removal of the crop is necessary to realize the removal of the nutrients and minerals which have been taken up by the plants and to renew the plants' capacity to accomplish this uptake as well as to realize any cash value of the crop as hay. Cutting of the crop is beneficial from an operating standpoint, because it eliminates the possibility of tall grass interfering with wastewater distribution. Experimental work conducted at Paris, Texas, indicated that it is possible to predict the time of year and stage of growth when hay of the highest value can be harvested [38, 24]. This is important in order to maximize crop value and nutrient removal capacity. In addition, it was found that a late fall harvesting not only resulted in a crop of less nutritional value, but also had adverse effects on the uptake capacities the following spring. This is an important consideration for year-round operations. Overharvesting can also reduce the removal potential of the cover crop. Further study is necessary to better define the effects of harvesting on performance.

Consultation with local farm advisers or agricultural extension service representatives can be helpful in planning a harvesting schedule. As mentioned previously, wastewater application schedules must be adjusted to permit harvesting. Scheduling of harvest can be complicated by rainfall in areas of the country that receive year-round precipitation. Harvesting must be done with care. The field must be allowed to dry sufficiently to prevent damage to the slope by harvesting equipment. Use of equipment with high flotation tires is helpful in this regard.

The use of soil amendments or fertilizers has not been necessary for the existing overland flow systems which are all treating cannery wastewaters. Application of the method to other types of wastewaters, which may be nutrient deficient, may require the periodic application of agricultural fertilizers to meet the needs of plants as well as the microorganisms in the soil. Application of high sodium wastewaters may necessitate the use of special management techniques to reduce the sodium concentration in the soil.

Protection of the cover crop from insect or other pests may require the use of pesticides. Experience at Paris, Texas, indicated that application of insecticides to control snails and army worms had no perceptible effect on the microbial population in the soil or on the performance of the system [38].

Monitoring – Monitoring is necessary to maintain loadings on the system within design limits. A routine monitoring program should be established to determine both the applied and runoff flow rates as well as selected influent and effluent quality parameters. Parameters of interest have been discussed earlier in this section under water quality considerations. These will, of course, vary in importance with the wastewater in question. If the runoff water is being discharged into a receiving water, regulatory agencies may require a specific monitoring program. Flow measurement and sampling equipment should be an integral part of the system design.

Monitoring of the groundwater is normally not required for an overland flow system because infiltration is minimal. The presence of a specific contaminant, however, may warrant such a monitoring program.

Treatment Efficiency – The performance of existing systems in terms of treatment efficiency has been impressive although only cannery wastewaters have been treated thus far. Effluent quality equals or exceeds that from conventional tertiary treatment processes. Removal efficiencies for several pertinent parameters are shown for the existing systems in Table 21. The facility at Paris, Texas, has been studied extensively in comparison with the others. On the other hand, the system at Davis, California, has completed its second season of operation and, although it is functioning well, definitive data have not been developed as yet.

The Paris studies confirmed that microorganisms normally found in the soil were responsible for oxidation of organic material. They also revealed that the removal efficiency did not decrease during the winter months. Decreased metabolic activity was compensated for by an increase in microbial population. In addition, it was found that drying of the slopes reduced the microbial population and thus the treatment efficiency, but recovery when spraying began again was normally quite rapid.

A portion of the nutrients are removed from the wastewater through luxury uptake by the cover crop and subsequent harvesting. This was evidenced by a phosphorus and nitrogen content in the harvested crop that was nearly double normal values [24]. Plant uptake alone, however, does not account for all the nitrogen removal, and volatilization and denitrification are probably occurring to some extent. The system also exhibited a large buffering capacity as indicated by the range of pH values in Table 21.

Operational Problems – Problems of existing installations have been primarily mechanical in nature and have been traced to design deficiencies. Some of the more notable problems are described here.

Table 21. Removal Efficiencies on a Concentration Basis for Overland Flow Facilities

Site location	BOD, mg/L			Suspended solids, mg/L			Total nitrogen, mg/L			Total phosphorus, mg/L			pH (range)	
	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent
Paris, Texas	490	8	98	245	24	90	19.0	3.0	85[a]	8.5	4.0	55[b]	5.1-9.3	6.2-8.0
Napoleon, Ohio	400	13	95	358	28	92	--	--	--	--	--	--	--	--
Chestertown, Maryland	800	5	99+	748	28	92	--	--	--	--	--	--	--	--

a. 90 percent removal was reported on a mass basis.

b. Up to 80 percent removal was reported on a mass basis.

At the Paris installation, numerous leaks developed in the air tubing connecting the automatic valves with the control panel. These leaks were difficult to locate because junctions were not marked. This problem was avoided in later installations by encasing all tube in conduits and locating all tubing junctions within a junction box [38].

Experience with control valves at the Paris facility demonstrated that butterfly valves did not seat tightly, resulting in continuous leakage from sprinkler heads. Inclusion of a magnetic brake on electric motor operators will eliminate this problem. The use of diaphragm valves in later installations avoided this problem.

The major nonmechanical problem, as with most other agricultural operations, has been the weather--specifically, rainfall at harvest times. This is less of a problem in areas such as California where the spring and summer are essentially free of rain. At the Paris installation, however, rainfall has resulted in several late harvests, the consequences of which were discussed previously.

LAND APPLICATION BY IRRIGATION AND INFILTRATION-PERCOLATION

Soils with fair to excellent drainage characteristics are more suitable for irrigation or infiltration-percolation than for overland flow. The distinction in loading rates between irrigation and infiltration-percolation will not be made here for industrial wastewaters. Current practice with these two methods ranges from light loadings with irrigation specifically for crop production to heavy loadings and the use of nonvegetated infiltration basins. Most systems operate well between these extremes, and the design and operating aspects of the various systems do not differ substantially.

System Design and Construction

There are no formulas by which a land application system may be designed. Each design requires participation of an engineer with extensive background knowledge of land application systems, a soil scientist, and an agronomist. Other specialists, such as hydrologists or geologists, may also be necessary [65]. Consequently, the discussion here is not aimed at establishing rigid standards, but rather at presenting important factors and related experience in design.

The major components of system design and construction include the following: (1) selection and preparation of a site with suitable drainage characteristics and sufficient area to accept the wastewater; (2) selection of design loading rates; (3) the design and installation of a wastewater distribution system and, where applicable, an effluent collection system; and (4) selection of suitable vegetative cover if one is feasible.

Site Selection and Preparation – Four basic site conditions must be considered when selecting an area for land application of wastewaters by irrigation or infiltration-percolation. These are: (1) the characteristics of the soil; (2) the subsurface hydrologic and geologic conditions; (3) the surface topography; and (4) the climate. The effects of these conditions on design and operation of municipal wastewater land application systems have been discussed in detail in Sections IV and V, and are equally valid in the case of industrial wastewaters. Therefore, the discussion here will be limited to considerations which apply specifically to industrial wastewaters.

As discussed in Section III, soils vary in their ability to remove or retain certain wastewater constituents. The industrial wastewater applied to a given soil must be compatible with the renovative capabilities of the soil. For instance, industrial wastewaters containing significant refractory organic, heavy metal, nutrient, or color concentrations should be applied to soils with high adsorptive capacities, such as loams, peats, or clay loams. Failure to match the soil to the wastewater can result in groundwater contamination, as has occurred at some installations where spent sulfite liquor has been applied to the land [12].

It has been demonstrated that removal of degradable organic material by a land application system is essentially independent of the soil type. Therefore, industrial wastewaters that are free of nondegradable contaminants can be and have been successfully applied to all soil types.

The use of underdrain systems to adapt to adverse subsurface geologic or hydrologic conditions, such as a high groundwater table or impervious subsoils, has been common for industrial systems. An example of the successful use of underdrains is the irrigation facility for poultry processing wastewater at Sumter, South Carolina (see Appendix A). Perforated drainage pipe was installed to allow utilization of the full depth of a highly permeable sand layer which was underlain by a relatively impervious sand-clay layer. Underdrainage also successfully solved the problem of limited lateral movement of water underground due to high water tables at board mill installations at L'Anse, Michigan, and Largo, Indiana.

Although underdrains may prove helpful in some cases, the consequences of their use should be considered. Use of underdrains will result in an effluent that must be collected and discharged. In addition, their use may reduce the removal efficiency of the system if sufficient detention time in the soil matrix is not provided.

Loading Rates – The land required for a system is determined from the flow rate of wastewater and the use of the loading rate that requires the largest acreage. Controlling loading rates may be (1) liquid or hydraulic, (2) organic, or (3) nutrient or other inorganic chemical. Most systems, according to reported information, are governed by the hydraulic loading rate, which is a direct function of the soil drainability. The wide variation in hydraulic loading rates used by current systems is illustrated in Table 22 for several selected installations. Operators of many industrial wastewater systems have determined the permissible hydraulic loading of a site through a series of trial and error stepwise expansions. From a planning standpoint this is not a desirable method. Operation of test plots is the preferred method of determining design loading rates although it is time-consuming and costly to do so.

The soil mantle has a limited capacity to adsorb and stabilize degradable organic material, without having detrimental effects on the terrain ecosystem. When this capacity is approached by the application of the wastewater, the organic loading rate becomes the limiting design factor. In general, organic loading will be limiting only for systems handling very high BOD wastewaters (greater than 10,000 mg/L). Defining the limiting organic loading rate for a system must be done on an individual basis. However, rule-of-thumb rates which can serve as a design guide have been developed. Extensive laboratory studies with various pulp mill effluents on four representative soil types indicated that a maximum BOD loading rate of 200 lb/acre/day could be used without detriment to vegetation or soil permeability, and a high degree of treatment could still be maintained [12]. There are, of course, substantially higher loading rates being used with success at several installations, as evidenced by some of the rates listed in Table 22. It should be noted, however, that these are seasonal rather than year-round operations. As mentioned previously, the nature of the organic material in the wastewater will affect the limiting organic loading. Wastewaters containing a high percentage of sugars, for instance, can be applied at a higher organic loading rate than wastewaters containing mostly starchy or fibrous material [93].

Table 22. Organic and Hydraulic Loading Rates of Selected Industrial Wastewater Land Application Sites

Site location or reference	Type of waste	Wastewater flow, mgd	Average BOD, mg/L	Average hydraulic loading in./day	Average organic loading, lb BOD/acre/day
Seabrook, New Jersey	Vegetable processing	16	--	12	--
[61]	Cannery	--	--	6.4	210
[122]	Corn processing	--	--	3.4	860
Bridgeton, New Jersey	Tomato processing	3	--	2.5	--
[68]	Kraft mill	1	1,000	1.8	420
Sumter, South Carolina	Poultry processing	3.75	520	0.9	110
L'Anse, Michigan [93]	Board mill	0.6	1,200	0.55	138
[4]	Citrus processing	0.82	3,300[a]	0.45	350
Acton, Canada [91]	Tannery	1.25	800	0.45	50 (600)[b]
Firth, Idaho	Potato processing	0.65	1,200	0.3	78
Fremont, Michigan [35]	Food processing	0.8	1,000	0.3	74
Fairmont, Minnesota	Food processing	1.5	1,500	0.1	47

a. Estimated from COD measurements.

b. Loading during spring.

Loading rates for nutrients or other chemical constituents normally are not limiting factors for industrial wastewaters suitable for land application. Exceptions to this on an industrywide basis are wastewaters from the dairy and meatpacking industries. Total nitrogen concentration due to milk spillage has been reported as high as 300 mg/L [59]. Application of this concentration of nitrogen at normal hydraulic loading rates would far exceed the nutrient uptake capacity of a cover crop and would undoubtedly result in leaching of significant quantities of nitrates into the groundwater. There will, of course, be individual processing plants with high levels of nutrients or chemicals in their wastewater as a result of specialized processing operations. In such cases, the possibility of loading limitation because of these constituents must be considered.

In some cases, pulp and paper installations in particular, nutrients may be deficient, and supplementary fertilizers must be added with the wastewater to promote cover crop growth and maintain biological activity in the soil. The soil must be tested initially and routinely to determine if sufficient nutrients are being supplied. Nutrient addition will be discussed further under "Operation and Management."

Distribution and Collection System – The major method of application of industrial wastewater has been with sprinklers. The ridge and furrow method has found limited application and flood irrigation even less. Spraying has become the predominant form of application for several reasons. Most importantly, sprinklers distribute the organic and solids load of the wastewater more uniformly over the site. This is important with relatively high strength wastewaters because it prevents portions of the site from becoming overloaded. Sprinkler systems are more readily adaptable to the widely varying wastewater flows which often occur in industrial processing. Additionally, there is less land preparation required with sprinkler application. The design of sprinkler systems has been discussed in detail in Section IV. It should be mentioned here, however, that the selection of the type of sprinkler system, permanent versus portable, etc., is a matter of economics and will depend on the operating season of the processing plant.

The ridge and furrow distribution method is best suited to smaller systems where close control of large volumes of wastewater is not required [84]. This method has also been applied to several systems where the wastewater is apparently toxic to vegetation [105, 91]. Level or very gently sloping land is required for ridge and furrow distribution to be effective. Additionally, the system should have relatively permeable soil to reduce the amount of surface clogging that may occur because of the deposition of solids.

The use of border strip irrigation with industrial wastewaters has limited applicability when a cover crop is used. Suspended solids contained in most industrial wastewaters are deposited at the head end of the strip or basin, overloading that area and choking out the vegetation. The method has been applied with limited success at a potato processing plant in Lewisville, Idaho, and at a tomato cannery in Thornton, California. It is better suited to systems which are operated as infiltration basins without vegetated surfaces. This system has been used effectively in the wine industry for disposal of stillage wastewaters [22].

The use of large seepage or percolation ponds, such as those used for groundwater recharge with municipal wastewaters, has not been feasible with industrial wastewaters. The relatively high BOD and suspended solids concentrations make aerobic conditions difficult to maintain in the upper soil layers. A method combining the principles of the ridge and furrow method and spread basins has been used to infiltrate citrus wastewaters. The method, referred to as back-furrowing, uses a system of interconnected furrows to spread the wastewater evenly over an area. The ridges between the furrows allow air to enter the soil and maintain aerobic conditions during spreading. Odors were thus eliminated, and infiltration rates were maintained at a much higher level than with seepage basins [4, 62].

If underdrain piping is employed, then effluent collection and discharge facilities must be included in the design. These items are covered under the discussion on the overland flow method.

Surface Vegetation – Systems that use sprinklers for wastewater application require some type of vegetative ground cover to prevent soil erosion and sealing of the infiltrative surface due to the action of water droplets [61]. There is one system reported that sprays very high strength sulfite liquor wastewaters onto nonvegetated fields, but not on a continuous basis. Between applications, the fields are rejuvenated by treating with gypsum and growing a cover crop.

The objective of most industrial wastewater land application systems is to maximize hydraulic loadings, thereby minimizing land area requirements. Experience at most industrial installations indicates that a cover crop is beneficial in helping to increase and maintain infiltration rates. The root structure tends to expand the soil and promote dispersion of clogging material [65]. Vegetation also increases the hydraulic capacity of the system through removal of soil water by evapotranspiration. This water consumption can be a significant portion of the applied wastewater for systems with low permeability soils. An excellent example of this is the food processing facility at

Fairmont, Minnesota, where essentially all of the wastewater applied is lost to the atmosphere by evapotranspiration and any runoff is collected and resprayed. Only for very permeable soil conditions is a cover crop not of significant benefit [105]. At some installations the industrial wastewater has proven toxic to vegetation. As mentioned previously, the ridge and furrow method of application has often been employed in such cases.

When maximum hydraulic loading is the objective of the system, the cover crop should be selected with this in mind. As mentioned under "Treatment by Overland Flow," hydrophytic, perennial grasses are the most suitable crop. These grasses have also proven to be more tolerant to the high organic loadings often used in industrial systems. Reed canary grass is the species that has been applied with widest success, although it normally requires considerable time to become completely established.

Some systems have applied wastewater to naturally vegetated areas and have relied on natural ecological succession to establish a suitable vegetative cover. The most notable examples of this approach are the food processing installations at Seabrook Farms, New Jersey, and Bridgeton, New Jersey, where wastewaters are loaded at very high rates on naturally wooded areas. However, for most systems, especially those with low or moderately permeable soils, it would be preferable to hasten the maturing of a system by the purposeful establishment of a hydrophytic species.

Cash crops, such as alfalfa, corn, and peanuts, have been successfully used as cover vegetation, but in many cases, attempts to maximize hydraulic loading at the site has resulted in overwatering and killing of the crop [32]. When such crops are grown, standard practices of irrigation must be used. Consultation with local farm advisers or agricultural extension service representatives on the subject of crop selection and suitable irrigation practice can be helpful.

Other Considerations - The design of a system must consider the climatic effects, such as rainfall and temperature variation, on the system. Designing for seasonal changes has been discussed at length in previous sections on municipal wastewaters. It is interesting to note here, however, the apparent disagreement in the literature on the feasibility of winter operation of industrial land application systems. Some systems, notably the Seabrook Farms and the Fremont, Michigan, facilities [35], provide continuous spraying of wastewater through the winter without adverse effects on the vegetative cover. At other systems, such as the tannery wastewater facility in Acton, Canada [91], it has been demonstrated that the buildup of ice on the soil is injurious to the vegetation. On the basis of this conflicting experience, it appears that the feasibility of cold weather application of industrial waste must be determined for each individual case.

Operation and Management

The operation and management of irrigation and infiltration-percolation systems has been discussed under the respective sections for municipal wastewaters. The reader is referred to those sections for a more detailed discussion on the subject. Specific considerations for industrial wastewater systems will be discussed here.

Loading Cycles – The cycling of wastewater application must be adjusted to avoid ponding of the wastewater on the field which results in prolonged anaerobic conditions in the soil mantle. The optimum loading cycle must be determined through experience for each individual system. Operating schedules reported in the literature commonly call for one day of application followed by several days of drying. An extreme case occurs for a system in Terre Haute, Indiana, which handles very high sodium pulping liquors. The system is operated until ponding begins to occur; then it is rested for several years [43].

Adjustment of the loading cycle will be required to compensate for changing weather conditions. The winter operation at the Fremont, Michigan, and the Seabrook, New Jersey, facilities entails continuous spraying from a few sprinklers to prevent freezing [35]. Odor problems have arisen at the Beardmore site in Canada as a result of the spraying of anaerobic wastewater which had been stored during the winter. The problem was minimized by loading the stored waste onto the land at a rate several times the normal operating rate [91].

As mentioned previously, growing of cash crops requires that normal irrigation practice be followed. In this regard it is often helpful to have experienced farm personnel operate the system.

Field Management – Field management activities include: (1) maintaining the infiltrative capacity of the soil surface; (2) harvesting of cover crops or otherwise controlling the vegetative cover if used; and (3) supplementing the soil with fertilizers or soil amendments as necessary.

Properly loaded systems with vegetative cover do not normally require mechanical assistance in maintaining infiltration rates. Systems without ground cover, however, do require disking or other tilling normally after each application to reopen soil pores and restore the infiltrative capacity of the system. The frequency of such operation must be determined individually for the system in question.

Harvesting of a cover crop is definitely required if nutrient removal is an objective of the system, and is obviously necessary if a cash benefit is to be realized. Scheduling the harvest for maximum crop value should be considered, as discussed under overland flow treatment.

Many systems report cutting but not harvesting of the vegetative cover. This procedure may be of benefit for systems that handle nutrient deficient wastewaters, as often found in the pulp and paper industry. The decay of cut vegetation will provide a recycle of plant nutrients, thus minimizing the need for supplemental fertilizers. Vegetative litter may also prove beneficial by providing additional media for microorganisms. A good example of this situation has occurred at the system in L'Anse, Michigan, which handles hardboard mill wastewater. There is a danger in generating too much vegetative litter, which can exert a substantial BOD loading of its own on the system and thus limit its renovative capacity. Matting of tall cut grass on the soil surface can hinder drying of the soil surface and thus promote anaerobic conditions. This situation was encountered at the tannery wastewater facility in Acton, Canada, and was remedied by cutting the grass at frequent intervals [91]. It is generally recommended that the ground cover not be allowed to grow too tall even if it is to be harvested. Tall vegetation can interfere with the operation of the distribution system, hinder soil drying, and promote the propagation of insects if ponding does occur.

The use of irrigated fields for cattle grazing has been attempted; however, it was found to require excessive land areas in order to prevent severe soil compaction as a result of cattle traffic [84]. Cattle also tend to brush and rub against the risers which results in breakage [44]. It is concluded that grazing is generally not compatible with most industrial wastewater land application systems.

Supplemental fertilizers may be required for systems handling nutrient deficient wastewaters. The frequency of fertilizer application should be determined through monitoring for soil nutrients. Lime or gypsum may be required for soils receiving high sodium waters, or waters with very high or very low pH values.

Monitoring — Monitoring of applied wastewater flow rates and quality, even if not specifically required by regulatory agencies, is good operating practice. Monitoring results provide a basis for process control and any future design. Monitoring is especially important if there is a potential for groundwater contamination as a result of applying specific pollutants to the land. In addition, the results gathered from monitoring programs provide the basis on which decisions regarding changes in loading rates or operational practices can be made.

Treatment Efficiency — It has been reported that the soil mantle is capable of removing essentially all degradable organic matter and most of the suspended solids from wastewaters even when loaded at rates up to 200 lb BOD/acre/day [12]. Successful operation has been reported for substantially higher loading rates when applied on a seasonal basis [4]. This excellent removal efficiency has been found to be independent of the soil type [12]. In an effort to maximize loadings, however, several cases of groundwater pollution have resulted, as discussed under "Environmental Effects."

An example of the organic and solids removal efficiencies for underdrained irrigation is shown on Table 23. The wastewater is from a poultry processing plant in Sumter, South Carolina. The hydraulic and organic loading rates, shown in Table 22 for this system, are moderate and typical of many installations. The effluent quality was determined after the wastewater had passed through 5 feet of sandy soil and was collected by the underdrains.

The removal efficiency of land systems with regard to refractory organics, such as lignins and pesticides, and inorganic chemicals, such as heavy metals and nutrients, is dependent on the soil structure. Generally, the higher the clay and organic content of a soil, the higher the removal capacity. Although the theory of the removal mechanisms is known, the practical application of the theory to actual installations has generally been lacking. There is a paucity of quantitative information in the literature on the removal efficiencies of soil systems with regard to the above constituents. This is an area requiring further study.

For systems using cover vegetation and moderate hydraulic loadings, nutrient removal is primarily a function of plant uptake. Clay soils will retain nutrients in the root zone

Table 23. Characteristics of Sumter Plant Wastewater

Characteristic	Raw wastewater	Treated effluent[a]
BOD, mg/L	518	4
Suspended solids, mg/L	233	74
Total solids, mg/L	475	224
COD, mg/L	708	36
pH	6.6	6.8

a. After passage through 5 feet of sandy soil.

longer than sandy soils, thereby providing a greater opportunity for removal. Aside from the extensive studies performed at Paris, Texas, for the overland flow system, very little has been reported in the literature on the nutrient removal efficiency of in situ cover vegetation.

Operating Problems – Operating problems can be placed in three general categories: (1) those related to system mechanical design and equipment failures; (2) those related to system loading and management; and (3) those related to natural phenomena. Problems encountered in the first category related to design are discussed under the overland flow method. A common problem reported in the literature for industrial installations is clogging of sprinkler nozzles that is due to failure in the pretreatment screening operations. Careful inspection and maintenance procedures are necessary to minimize this type of problem. Using too small a nozzle size has resulted in frequent nozzle clogging at some installations [44].

Under the second category, the most common problem encountered is odor production from storage or settling ponds. This problem and its remedies are discussed under the section on pretreatment. Damage to cover vegetation caused by hydraulic and organic overloads has also been a common occurrence. Avoiding this problem is a matter of knowing the capacity of the system and operating within that capacity. Haphazard operating procedures are an invitation to problems.

Problems in the third category include primarily those resulting from the weather, although vandalism should also be mentioned. Rainfall can disrupt harvesting operations and unusually intense rainfall can overload and damage the system. An adequate safety factor must be used in the system to deal with such design occurrences. There are, of course, problems associated with operation during freezing weather. The major ones include pipe freezing, vegetation damage caused by ice buildup, and loss of treatment efficiency. Operating procedures to mitigate such problems have been discussed previously.

ENVIRONMENTAL EFFECTS

The effects of land application of wastewater on the soil ecosystem have been identified in previous sections and are discussed to some extent under pretreatment requirements in this section. The discussion here will be limited to important environmental effects particular to industrial wastewater land application systems.

Organic Overloading

Organic overloading can have a marked effect on the soil vegetation and groundwater. Laboratory studies conducted on pulp and paper wastewaters indicated that when the organic capacity of the system is exceeded, vegetation is damaged or killed completely, anaerobic conditions develop which lead to severe clogging of the soil, and undegraded organic matter is leached through the soil and can enter the groundwater [12]. These effects were confirmed in the field at an experimental system in L'Anse, Michigan [107]. The system was loaded at a rate of 2,000 lb BOD/acre/day. The vegetation was quickly killed, and the soil permeability was reduced substantially.

Sodium Effects on Soil

The effects of sodium on clay soil permeability is dramatically illustrated by the pulping mill wastewater system in Terre Haute, Indiana, which handles wastewater containing sodium concentrations in the range of 16 percent of the dry solids. The sealing effect of the sodium is so severe that the fields must be rested several years and treated extensively with gypsum before they recover. Sodium effects on overland flow systems are less critical because the infiltration rates of the soils are already quite low.

TDS Effects

The effects of dissolved salts on the vegetation and groundwater is of primary concern to industries which produce high TDS wastewaters. A good example of the situation that can develop is the tannery system at Acton, Canada. The wastewater there has a salt concentration reaching 3,000 mg/L. Leaching of this salt through the soil has substantially raised the salt concentration of the groundwater in the area. Although concentrations have not reached U.S. Public Health limits, complaints by local residents are threatening the existence of the plant [91].

Effect of Mosquito Propagation

At several California installations the major adverse environmental effect has been the propagation of mosquitoes due to hydraulic overloading of the spray fields. At Hunt-Wesson, Davis, California, the problem was anticipated, and mosquito fish or gambusia were planted in the runoff collection sump. For spray irrigation, ample drying must be scheduled in the operation to prevent massive mosquito propagation.

SECTION VII

CLIMATIC CONSTRAINTS ON LAND APPLICATION

Climatic constraints on land application and the effects of systems on the climate have been discussed individually in Sections IV, V, and VI for irrigation, infiltration-percolation, and overland flow. The intent of this section is to present a comprehensive discussion of (1) climatic classifications within the United States as they affect land application systems, and (2) local climatic effects from operation of large land application systems.

CLIMATIC CLASSIFICATION FOR LAND APPLICATION SYSTEMS

Climates can be studied, analyzed, and finally classified in many different ways depending on the purposes for which the classification is to be used. A climatic classification for agricultural purposes is quite different from one for human comfort, or for water resources. Thus, any consideration of the climatic constraints to land application techniques leading to a division of the climates of conterminous United States into large and fairly homogeneous regions, on the basis of their influence on the type of operation of land application systems, may result in a classification entirely unlike those achieved for other purposes.

Before one can begin to discuss the geographic variations in land application techniques imposed by climate, it is first necessary to understand how climate may influence the operation of a land application facility and what climatic factors can be considered truly "active" in terms of controlling the success or failure of a treatment system. It is clear that important climatic factors must involve elements of heat and moisture. In irrigation and overland flow systems, the vegetation cover is certainly a major contributor to the success of the systems. Vegetation requires moisture and both the rate of growth of vegetation and of decomposition of many solids in the effluent are regulated in large part by the energy available. Thus, climatic factors, such as "effective precipitation" (that part of the precipitation which enters the soil and is useful for plant growth and development) and net radiation (the balance between the incoming and outgoing radiation, or the usable energy at the earth's surface), are much more important and deterministic than are the standard degrees of temperature or inches of precipitation. Thornthwaite [127], Thornthwaite and Mather [128], and Mather and Yoshioka [75] have all identified the active factors of climate for vegetation growth and development as potential and actual evapotranspiration, the moisture index (made up of indices of humidity and aridity) thermal efficiency, and precipitation effectiveness. These somewhat complex sounding terms and indices all involve ways of expressing the influence of the energy and moisture factors in climate on the growth and well-being of vegetation or on the progress of biologic activity.

Energy Constraints

The major climatic constraint to the operation of a land treatment facility clearly involves the energy necessary for plant growth and the continuation of biologic decomposition. Energy receipts are directly related to latitude since the sun ultimately is the source of the energy received by the earth's surface. In winter, both daylength and the sun's angle decrease northward. Less intensity of energy is received for a shorter period of time so total receipts of energy decrease rapidly northward; the intensity of cold conditions increases markedly. In summer, daylength increases to the north while the angle of the sun's rays still decreases northward. The opportunity to receive energy for a longer period of time somewhat balances the decreasing intensity of radiation as one goes northward so that total receipts of energy are much less variable latitudinally in summer than in winter. This seasonal difference in energy receipts is reflected in latitudinal differences in air temperatures. July temperatures at Des Moines, Iowa, average 77.4 deg F while temperatures average 81.1 deg F in the same month in New Orleans, less than a 4 deg F difference. In January, the average Des Moines temperature is 22.6 deg F while at New Orleans it is 54.1 deg F, a difference of over 31 deg F. Thus, clearly, in defining climatic constraints to land application, one would expect a strong latitudinal variation because of the significantly different energy receipts especially in the winter season of the year, or because of the strong dependence of annual temperature range (difference between highest and lowest temperatures for the year) on latitude.

Moisture Constraints

Moisture constraints to efficient operation of land application systems also exist. Here, the problem is twofold. First, climates differ appreciably across the United States in both total annual amount of precipitation and in seasonal distribution. In general, in eastern and central United States, precipitation is fairly well distributed throughout the year although it decreases in total amount to the north because of the general decrease in air temperature. Cold air holds less moisture at saturation than warm air. A similar degree of cooling of saturated cold and warm air will release more moisture from the warm air than from the cold air. Total precipitation amounts decrease westward across eastern and central United States because of increasing distance from one major source of moisture, the Gulf of Mexico. North Dakota has the lowest total precipitation of any state east of the Rocky Mountains.

In the western United States, there are areas like the deserts and steppes of the Great Basin area or the southwestern states with little or no precipitation at any time of the year, while the more coastal areas of California experience marked seasonal patterns in rainfall. In the so-called Mediterranean climates of California, there is a clearly defined winter wet season and a summer dry season. Thus, the climates of California are quite distinct from those of Arizona and New Mexico, and both of these are quite different from the fairly well distributed patterns of precipitation found throughout most of eastern and central United States. While other patterns of precipitation exist in the United States, these three major subtypes, on the basis of total amount and seasonal distribution, appear to be most influential in terms of land application operations.

The second moisture problem relates to the intensity of storm precipitation. If the month's rainfall is well spaced through the month, a larger proportion of the precipitation will be able to infiltrate and to be lost from the upper soil layers by evapotranspiration and deep percolation. There should be little effect on the land application system. If, however, the month's precipitation comes as a result of one or two intense storms, all of the water will not infiltrate, there will be runoff, ponding in low areas, erosion, and the opportunity for effluent in the land application area to be washed into the surface watercourses and out of the treatment area without adequate decomposition. Greater care has to be taken in areas of possibly intense precipitation to prevent surface runoff from developing. While all areas of conterminous United States can experience intense short-period storm rainfall, it is clear that lower latitude areas where intense thundershower activity, hurricanes, and squalls are most frequent, are the areas of prime concern in this regard.

Heat and Moisture Effects

Heat and moisture factors influence the operation of a land application system in several important ways. First, in all such systems, there is the need to have the land area adequately covered by vegetation not only to prevent erosion but also to serve as the habitat for the microorganisms that ultimately break down and digest any solids removed from the effluent. For vegetation development, energy combined with adequate amounts of moisture are prerequisites. Most places in conterminous United States have sufficient energy for the development of a good ground cover of vegetation (although the composition of this cover may change from one region to another). Adequate amounts of moisture during the growing season are not found in all areas and so in some areas (or in nearly all areas at some time) fresh water supplies for irrigation purposes may be necessary during the period of development of the vegetation cover or to keep vegetation healthy during periods when use of the system is not contemplated.

Second, energy is required in the process of breakdown of the organic material removed from the effluent. The rate of microbial activity is directly related to the available energy as expressed by the temperature. It has been observed that bacterial reaction rates double with every 18 deg F rise in temperature until some limiting temperature is reached [80]. According to the temperature range in which they function best, bacteria may be classified as psychrophic (54 to 64 deg F), mesophilic (72 to 104 deg F), or thermophilic (131 to 149 deg F) [80]. Most soil temperatures are suitable for the development of mesophilic bacteria which can survive at temperatures up to 113 deg F. At temperatures above this maximum, the rate of oxidation of solids again slows. Since in a land application system adequate moisture should always be present to maintain evaporative cooling of the surface layers, this maximum temperature is seldom reached.

Third, energy receipts are directly related to evapotranspiration. While most land application systems are not primarily designed to dispose of all effluent by evapotranspiration, such a water loss must certainly be considered in any overall water balance of the treatment area.

During periods of high temperatures (> 75 deg F mean daily temperatures) more than 0.2 in./day of evapotranspiration can occur. This is equivalent to over 27,000 gal. of water loss per acre every 5 days. In periods without rain, this appreciable loss from the system results in less water infiltrating or running off over the surface. Annual values of evapotranspiration from an always moist surface vary from over 40 inches across Florida, southern Alabama, Mississippi, Louisiana, Texas, and the lower-lying areas of southern California and Arizona to less than 25 inches through New England, New York, Michigan, Wisconsin, Minnesota, the Dakotas, and most of the Rocky Mountain states. Since summer temperatures are not that different, as has been noted, it is the total length of the period of evapotranspiration that results in these significant differences from south to north across the country.

Fourth, the length of the below freezing winter period is quite important in the selection of the land application system. Land application is possible at low temperatures as long as the effluent does not freeze in the distribution laterals or in the spraying equipment. However, little purification occurs at temperatures near or below freezing and the effluent may freeze into big mounds of ice around the places where it is being applied to the land, possibly harming the vegetation. Most systems must be designed to store effluent or to utilize other means of treatment during such low temperature periods. A nationwide mapping of soil temperatures as related to ambient air temperatures would be helpful in planning land application facilities.

Fifth, as has been mentioned previously, adequate moisture is necessary not only for the development of the vegetation cover but also for the survival and well-being of the microorganisms that serve to break down the solids removed from the effluent. This is usually not a problem in a land application system since adequate effluent is usually available to prevent undue drying of the surface soil layers.

Sixth, the type of system employed must consider not only the daily anticipated loading of effluent but also any possible overloads resulting from heavy rainstorms. While the additional rainwater will dilute the effluent already applied to the land, this is of little value if that effluent is already very heavily loaded with solids and with a high BOD. Possibly more critical are the effects of the additional rain from long duration, low intensity storms. These storms provide little dilution and yet greatly affect the moisture balance. Some leeway must be incorporated into the design of land application systems in anticipation of both intense short period rainfall occurrences and long duration, low intensity rainfall.

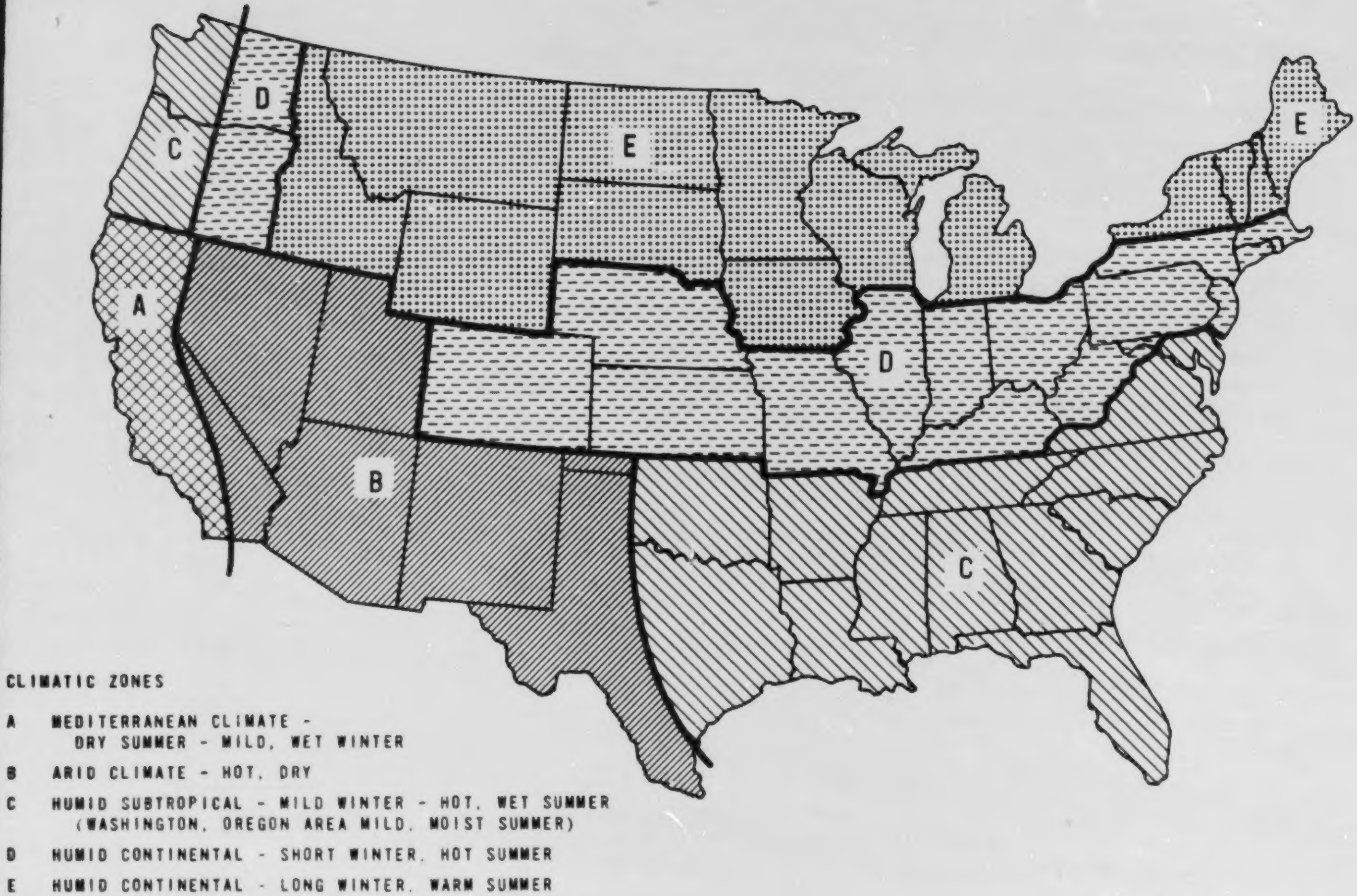
CLIMATIC ZONES FOR LAND APPLICATION

On the basis of the foregoing climatic analysis, it is possible to subdivide conterminous United States into a relatively small number of zones or areas in which climatic conditions pose quite similar constraints to the operation of land application systems. Of course, microclimatic differences or local soil, vegetation, or slope conditions within these broad areas might outweigh the general climatic considerations in the selection of the type of system. Still, within the large areas depicted, the major climatic factors of energy and moisture are similar enough to suggest similar methods of land application although local considerations must be carefully analyzed before any final decision is achieved.

In preparing a map (Figure 10) showing five general climatic zones in conterminous United States for land application purposes, the user and his understanding of climate has been kept carefully in mind. Thus, the map is not intended for the climatologist but rather for the engineer, the state or local official, or others who are concerned with land application but who do not have a great deal of knowledge about climate and its variation from place to place. The first effort has been to use state borders to outline the climatic zones if at all possible. Climates do not, of course, change abruptly at state boundaries but since such boundaries are simple to utilize for descriptive or regulatory purposes, their use was dictated here.

The map has two major features. First, there is a general east-west zonation, east of the Rocky Mountain area which represents the general decrease in temperature as one goes northward across the United States. Second, there is also some slight north-south zonation, especially across the western United States, representing the general change in precipitation amounts and seasonal distribution found in this area. Average monthly temperature and precipitation values for representative stations in each of the five climatic zones are listed in Table 24.

Zone A, which covers California except for the extreme southeastern part, delineates the unique Mediterranean climatic region with its marked seasonal pattern in precipitation. This area has essentially no rainfall in the summer months and a precipitation maximum in winter. Average annual precipitation is about 15 to 25 inches confined generally to the 6 months from November to April;



CLIMATIC ZONES

- A MEDITERRANEAN CLIMATE - DRY SUMMER - MILD, WET WINTER
- B ARID CLIMATE - HOT, DRY
- C HUMID SUBTROPICAL - MILD WINTER - HOT, WET SUMMER (WASHINGTON, OREGON AREA MILD, MOIST SUMMER)
- D HUMID CONTINENTAL - SHORT WINTER, HOT SUMMER
- E HUMID CONTINENTAL - LONG WINTER, WARM SUMMER

FIGURE 10
GENERALIZED CLIMATIC ZONES FOR LAND APPLICATION

Table 24. Average Monthly Temperature and Precipitation Values at Representative Stations in Each of the Five Climatic Zones

Zone	Location		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
A	Sacramento, Calif.	T[a]	46.2	50.2	54.3	59.9	66.0	72.5	77.4	76.1	73.6	64.9	54.3	47.5	61.9
		P[b]	3.19	2.99	2.36	1.42	0.59	0.12	Trace	0.04	0.20	0.79	1.46	3.23	16.30
A	Los Angeles, Calif.	T	55.8	57.0	59.4	61.9	64.8	68.0	73.0	73.0	72.0	67.5	62.8	58.3	64.4
		P	3.07	3.35	2.24	1.18	0.16	0.08	Trace	0.04	0.24	0.39	1.06	2.87	14.69
B	Midland, Tex.	T	44.1	48.4	55.2	64.9	73.4	81.1	82.9	82.2	75.4	65.8	52.5	45.9	64.2
		P	0.79	0.59	0.35	0.83	2.09	1.61	1.89	1.50	1.77	1.65	0.47	0.67	14.25
B	Phoenix, Ariz.	T	50.7	54.5	60.4	68.7	77.0	85.6	91.2	89.1	84.4	72.1	59.2	52.5	70.5
		P	0.75	0.87	0.67	0.31	0.12	0.08	0.79	1.10	0.75	0.47	0.47	0.87	7.20
C	Macon, Ga.	T	49.3	51.1	56.8	65.7	73.9	80.8	81.9	81.3	76.5	66.2	55.4	48.9	65.7
		P	3.39	4.25	4.92	3.74	3.31	3.35	5.63	4.17	2.76	2.01	2.44	4.06	44.09
C	Little Rock, Ark.	T	40.6	44.4	51.8	62.4	70.5	79.0	81.9	81.3	74.3	63.1	49.5	41.9	61.7
		P	5.24	4.33	4.80	4.92	5.28	3.62	3.35	2.83	3.23	2.87	4.13	4.09	48.66
C	Portland, Ore.	T	38.5	42.1	46.0	51.8	57.4	62.1	67.3	66.6	62.2	54.1	45.1	41.4	52.9
		P	5.35	4.21	3.82	2.09	2.01	1.65	0.39	0.67	1.61	3.62	5.31	6.38	37.17
D	Columbus, Ohio	T	31.6	32.7	40.5	52.0	63.1	72.7	76.5	74.8	67.8	56.5	43.3	33.4	53.8
		P	2.91	2.20	2.87	3.35	3.46	3.78	3.66	2.80	2.32	1.89	2.24	2.24	33.74
D	Omaha, Neb.	T	22.3	26.4	36.9	51.6	63.0	73.0	78.4	76.3	66.9	55.8	38.8	28.2	51.4
		P	0.83	0.94	1.46	2.56	3.46	4.53	3.39	3.98	2.64	1.73	1.26	0.79	27.56
D	Spokane, Wash.	T	25.3	30.0	38.1	47.3	55.8	61.3	69.4	67.5	59.9	48.6	35.2	29.7	47.3
		P	2.44	1.85	1.50	0.91	1.22	1.50	0.39	0.39	0.75	1.57	2.24	2.44	17.20
E	Albany, N. Y.	T	25.7	26.8	35.8	48.4	59.9	69.1	73.9	71.8	63.7	53.1	41.7	29.5	49.8
		P	2.52	2.24	2.87	2.91	3.62	3.74	4.29	3.31	4.02	2.83	2.91	2.72	37.95
E	Huron, S. D.	T	12.6	16.5	28.8	45.0	57.6	67.6	75.0	72.9	61.9	48.7	31.3	18.9	44.8
		P	0.47	0.59	1.10	1.85	2.36	3.15	1.81	2.09	1.54	1.14	0.67	0.55	17.32

a. Temperature, deg F.

b. Precipitation, in.

practically no precipitation falls in the other 6 months of the year. Temperatures are mild in winter and hot in summer so that there is adequate energy in almost all seasons for some plant growth. Storage of effluent due to freezing will not be necessary but may be desirable because winter crop needs will usually be lower than those in summer. Data for Sacramento and Los Angeles in Table 24 are typical of conditions in Zone A.

Zone B covers the area of Nevada, Utah, Arizona, and New Mexico, as well as the eastern portion of California and the western portion of Oklahoma and Texas. This zone represents the very hot arid climates of conterminous United States. They experience large receipts of energy in most seasons of the year. Winter storage of effluent should not be a concern although there are cases, such as at Portales, New Mexico, where winter storage is used. There may also be problems of salt in the soil if groundwater or brackish water is used in irrigation or constitutes a significant portion of the effluent. Clearly these climatic conditions do not describe the mountainous areas where, because of elevation and orographic effects, temperatures are considerably cooler and precipitation more adequate. Thus care must be exercised in designing land application systems in Zone B because of great local variations in climatic conditions. However, the general climate of the region can be fairly well represented by conditions at Phoenix, Arizona, and Midland, Texas.

Zone C covers primarily the states identified as the Mid- and Deep South. This means all states south of and including Oklahoma, Arkansas, Tennessee, Virginia, Maryland, and Delaware, except for the panhandle areas of Oklahoma and Maryland. In addition, the western portions of Washington and Oregon are included in this zone. This is classified as a generally humid subtropical type of climate with precipitation fairly well distributed through the year (with the possible exception of western Oklahoma and Texas), and with hot, muggy summers and fairly mild winters. In general, precipitation varies from 40 to 60 inches during the year, and temperature ranges from the low 40s in winter to the low 80s in summer. These ranges do not hold for the Washington-Oregon area which experiences mild winters as well as mild summers. This latter area is included within Zone C because it has sufficient moisture from precipitation through the year (the Washington-Oregon area will have low precipitation in mid-summer for about 2 months) for the growth of vegetation and the temperatures are mild enough to eliminate any real danger from winter freezing. Twelve-month operation of a land application system is possible in most areas of Zone C as it is in Zones A and B.

Little Rock, Arkansas, Macon, Georgia, and Portland, Oregon, provide typical climatic data for Zone C stations.

Zone D covers eastern Oregon and Washington as well as the central tier of states running in a band eastward from Colorado through Missouri and Illinois to Pennsylvania and New Jersey and into southern New England, including Massachusetts and southern New York. The climate can be described as humid continental, having moderately cold winters (temperatures in the 20s and low 30s), hot summers (temperatures in the mid-70s), and precipitation well distributed through the year. The precipitation is entirely adequate in the eastern portion but it is on the low side in the western portion (Colorado, Nebraska, Kansas, as well as Washington and Oregon). In general, there is sufficient moisture to start vegetation on a land application area or to keep it thriving if the system is unused for a while but small amounts of irrigation might be needed in the western portion. Winter temperatures are cold enough that storage of effluent for a month or two might be necessary. Data from Omaha, Nebraska, Columbus, Ohio, and Spokane, Washington, represent climatic conditions existing in Zone D.

Zone E covers the northernmost tier of states from Idaho eastward across the Dakotas to Iowa, Wisconsin, Michigan, and northern New England. These might also be called humid continental climates but with very cold winters. Precipitation occurs in all months of the year and averages 20 to 40 inches per year. Summer energy receipts are also sufficient for the development of a good vegetation cover. Winter operations are quite limited because the bitterly cold winter temperatures, with ice and snow, require the storage of effluent for anywhere from 2 to 6 months. The cold period is fairly continuous so that essentially no periods exist during the winter months in which irrigation is possible. Data from Huron, South Dakota, and Albany, New York, might well represent conditions in this area.

The five broad zones illustrated in Figure 10 provide a fairly simple and general classification of climates in conterminous United States for the purposes of land application operations. They should be considered only as approximate, and climatic data from the immediate vicinity of any proposed land application operation should be studied in detail before any final decision concerning type of system is made.

LOCAL CLIMATIC EFFECTS FROM OPERATION OF LAND APPLICATION SYSTEMS

Any discussion of the influence that large land application systems might have on local climates must clearly focus on energy and moisture factors. While man's influence on his environment already has been great, his influence on the climate has so far been of rather local consequence. The cities he builds, the swamps he drains, or the reservoirs he creates have changed the factors of the heat and moisture balance over rather limited areas. The reason for this lies mainly in the relative magnitudes of heat and moisture involved in man's activities as compared with those already available in nature. For example, Huff and his associates [46] calculated an evaporation rate of 29,400 gpm or 2.2 tons/second from cooling towers used with a 2,200-megawatt nuclear power plant. At the same time they showed that the water flux into a medium-sized thunderstorm might be of the order of 8.3 tons/second, nearly 4 times the amount of water being evaporated in the cooling towers. Computations on a large-sized cumulonimbus--a thunderstorm with hail--provided a value of 1,650 tons/second of moisture flux through the base and into the cloud. These values found in nature are some 75 times larger than those produced by man through the operation of very large cooling towers.

The same authors provided one further comparison by calculating the flux of atmospheric water vapor through a vertical section of the atmosphere 1 kilometer high and 10 kilometers wide (about equal to 4 square miles) with air of specific humidity of 10 grams/cubic meter and a wind velocity of 10 meters/second (23 mph). The moisture conditions specified are quite realistic, being equivalent to saturated air at 57 deg F or air at 50 percent relative humidity at a temperature of about 77 deg F. Using such figures, it can be shown that some 1,100 tons/second of moisture would pass through the vertical section or about 500 times the moisture flux from the cooling towers. Such computations can be repeated many times; they continue to show that the quantities of heat or moisture involved as a result of man's action are usually quite insignificant when compared with the quantities of heat or moisture already present in the environment.

The operation of a large land application system for wastewater can be considered to be similar to a large irrigated tract or even to a large water body (reservoir or lake). The extensive moist surface will modify atmospheric conditions in several distinct ways. First, air over large water bodies always experiences smaller diurnal and seasonal changes in temperature than air over nonirrigated or drier surfaces. Water has a higher specific heat than soil so that it will take a greater input of heat to cause a water surface or moist soil to warm, say, 5 deg F than it will a dry soil surface. With a greater heat capacity, the moist surface will not cool as rapidly at night so that the diurnal swings of temperature at the surface and in the air above it will be less than over a dry surface. The same argument applies to the annual ranges of temperature; the effect of a large lake or moist tract is to reduce the summer peaks of temperature as well as to prevent the winter extremes of cold temperature.

The second influence of large moist tracts or lakes would be to increase the moisture content of the air over the tract and downwind from the tract itself. Because of the significant evaporation of moisture into any air mass passing over the moist area, the air should be brought close to saturation; atmospheric humidities downwind of the moist tract should be appreciably higher than they are upwind from the tract. To condense moisture out of air, it is necessary to cool the air below its dew point temperature (the saturation point). Thus, if air, after moving off the moist tract or lake moves upward over a rising land surface or is cooled in contact with a snow surface, some condensation of moisture may occur in terms of fog, clouds, or possibly precipitation.

While the foregoing indicates the types of changes that will occur as a result of the operation of a land application system, the actual magnitudes of the changes that result are still in question. Very few actual measurements around such systems, under different climatic conditions, exist. It is possible, of course, to obtain some information by considering the types of changes that have occurred around lakes and reservoirs or, in a few instances, around large irrigation enterprises where observations have been made. The following paragraphs describe a few results that might serve to put the type of changes from a land application system into proper perspective.

Effects on Climate Resulting From the Creation of Reservoirs

Rybinsk reservoir, located in northern Russia, somewhat north and east of a line between Moscow and Leningrad, covers about 4,570 square kilometers in area (about 1 million acres). It is a fairly large but shallow body of water in a humid continental climate (equivalent to Zone E on the climatic map of conterminous United States). The reservoir has been filled for more than 25 years so that it has been possible to study conditions at many stations around the reservoir, both those influenced by the presence of the reservoir as well as those far enough away to be uninfluenced by its presence.

Vendrov and Malik [132], summarizing some of the results achieved by others, indicate that the climatic change produced by the reservoir seems to be limited almost entirely to the water area of the reservoir itself and to a narrow shoreline zone several hundred yards wide. For example, some investigators report diurnal temperature ranges just 0.6 mile inland from the reservoir shore were identical to ranges found at much greater distances inland from the reservoir. Other investigators have found this zone to be slightly wider than 0.6 mile.

By comparing data at stations in existence before and after filling of the reservoir, Vendrov and Malik conclude that the change in local climate is actually noticeable in a zone about 6 miles inland from the reservoir. In fact, they established two zones of influence of the reservoir: (1) a 6-mile wide zone of permanent active influence, and (2) a zone running some 18 to 30 miles inland from the shore in the downwind direction (and smaller distances in other directions) in which episodes of influence are interspersed with other periods of no influence. These authors found that:

> At the beginning of the warm season, the reservoir has a cooling influence, and in the second half of the warm season a warming influence on the surrounding region. Judging from the mean daily temperatures, the cooling influence makes way for a warming influence in the second or third decade of July. The transformation of day and night temperatures differs in character. For the greater part of the warm season (including August), the reservoir cools its surroundings substantially in the day, and then warms them very slightly in September and October. Most of the warming effect of the reservoir is at night [132].

The same authors find that the diurnal temmperature range decreases within the entire zone of active influence, the decrease being largest in summer and less significant in autumn. More than 6 miles from the reservoir surface, some change in diurnal temperature can be found in some years (usually those with very warm summers) but not in others. Along the southern border of the reservoir a decrease in maximum temperatures and an increase in minimum temperatures can be found as far inland as 30 miles.

> The effect of the reservoir on relative humidity is limited to a relatively narrow belt up to 10 km [6 miles] wide. On the northern shore, the width of the belt is apparently 5-6 km [3-4 miles] and changes in relative humidity at points 10 km inland can be traced only in the daytime in warm-summer years [132].

Vendrov and Malik list the following quantitative changes within the zone of active influence of the reservoir. The diurnal temperature range was decreased by as much as 2.9 deg C. The monthly maximum temperatures were reduced as much as 3.5 deg C and the monthly minimum temperatures were raised as much as 4.6 deg C. Also, in the zone of influence the relative humidity increased as much as 18 percent [132].

The results from the Rybinsk reservoir are similar to those found elsewhere. For example, Borushko [13] indicated that the 8-mile wide Tsimlyansk reservoir influenced air temperature and relative humidity conditions over a 2- to 3-mile distance inland from the shore. Kolobov and Vereshchagin [52] found that the width of the active influence zone was 4 to 6 miles around both the Kuybyshev and the Volgograd reservoirs. Dubrovin [29] suggested the influence of the Kuybyshev reservoir on absolute humidity extended 3 to 4 miles inland and this conclusion has been substantiated by other investigators.

Effect of Large-Scale Irrigation on Climate

Sokolik [116] made a detailed study of the effect of an irrigation enterprise in an arid region of Russia on the heat regime of the surrounding area. Because of the rapid evaporation of moisture into the air at the upwind edge, there is a marked decrease in air temperature in the first 3,000 feet of movement across the irrigated tract. Further movement across the irrigated tract results in only a small further decrease in temperature. Moving out of the irrigated tract and over dry land again, the air very rapidly increases in temperature due to turbulent mixing. Half of the temperature drop is regained within the first 600 feet of movement over the dry area while the remainder of the temperature change is regained within another 3,000 feet; some 3,600 feet inland from the downwind edge of the irrigated tract the temperature is the same as it was upwind of the tract. The results, included schematically in

Figure 11, emphasize the relatively small influence of an irrigated tract on local climatic conditions.

Effect of Evaporation From Irrigation Sprays

Mather [74] investigated the evaporation of water being sprayed from fixed overhead irrigation pipes and by large rotating sprinklers. While the rate of evaporation is about the same in both cases, the percentage of the applied water that actually evaporated was considerably less in the case of the rotating sprinklers since these sprinklers applied a much greater volume of water per hour. The results of a few evaporation tests are summed in Table 25. The figures show that as the distance downwind in the irrigated tract increases, the rate of evaporation into the air becomes less. The greatest increase in the moisture content in the air occurs in the first few meters within the irrigated area. Thereafter, the moisture increment becomes smaller with increasing distance and will finally drop to

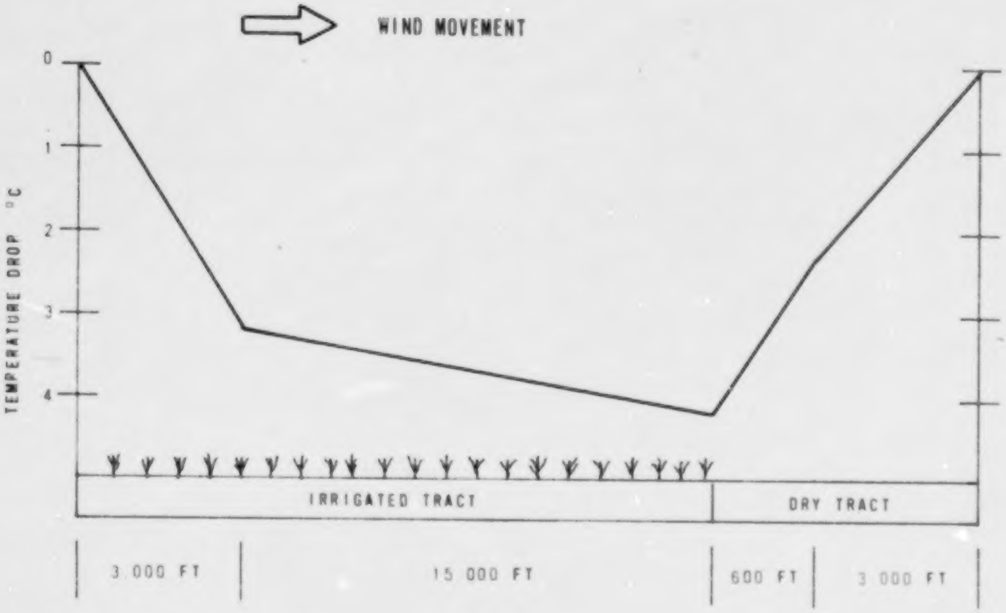


FIGURE 11
TEMPERATURE CHANGE OVER AN IRRIGATED TRACT [116]

Table 25. Dew-Point Temperature, Wind, Weather, and Evaporation Observations in Fields Irrigated by Overhead Irrigation Lines

	Aug. 19, 1949	Aug. 20, 1949	Aug. 27, 1949
Irrigation rate	0.09 in./hr	0.09 in./hr	0.09 in./hr
Wind velocity	6.5 mph	4 mph	5 mph
Sky	Scattered clouds	Scattered clouds	Clear
Crop	Broccoli	Broccoli	Broccoli

	Upwind[a]	Downwind[b] 40 m	Downwind 60 m	Upwind	Downwind 40 m	Downwind 80 m	Downwind 120 m	Upwind	Downwind 45 m	Downwind 100 m
Dew-point observed, deg C										
7 meters[c]	17.0	17.0	16.8	10.1	10.6	10.5	10.3	23.0	23.0	23.0
3 meters	17.5	18.0	18.1	10.4	10.6	10.7	10.8	23.3	23.6	23.8
0.5 meters	17.8	18.7	18.5	11.3	12.0	11.9	11.9	23.5	24.0	24.6
Evaporation, percent[d]		28	21		14	7	4		17	14
Evaporation increment, percent[e]			3			0	0			9

a. Observation taken upwind outside irrigated area.

b. Observation downwind. Distance downwind within irrigated area indicated in meters below.

c. Height of observation above ground.

d. Indicates evaporation as percentage of application from upwind to that observation point.

e. Indicates evaporation as percentage of application between indicated observation points within irrigated area.

almost zero when the air nears saturation. The width of this border area of rapid increase in moisture content of the air depends on meteorological conditions as well as on the amount of irrigation. Analysis of the figures in Table 25 suggests that only in the first 40 meters within the irrigated area is there much gain in moisture content in the air. Clearly, less water is lost by evaporation in an irrigation project if the size of the field irrigated is made as large as possible.

Climatic Influences of Cooling Towers

To put the climatic effects of large land application systems into perspective, a comparison is drawn with large cooling towers. Conditions around a cooling tower are not entirely comparable to conditions around a land application system since the tower releases vast amounts of heated air along with the moisture evaporated. The land application system will put moisture into the air but will not release significant amounts of hot air to the atmosphere at the same time. In the case of the cooling tower, the moisture is inserted at essentially a point source while in the land application site the source may be a square mile in extent. These differences would suggest that conditions downwind from the cooling towers should be changed to a greater degree than they would be downwind from a land application system. Yet, investigators minimize the downwind effects of cooling towers on atmospheric conditions. Thus, downwind effects of land application operations should also be minimal.

Lacking quantitative information on the environmental influence of cooling towers, most researchers feel that some changes in frequency or severity of fog, icing, clouds, precipitation, and possibly severe weather such as thunderstorms may result. Increased frequency of fog and icing conditions appear to be more likely to develop from the use of short cooling towers while taller-type towers may result in plumes that do not sink to the ground so that only clouds develop. With the shorter (75- to 100-foot) towers, McVehil [71] suggests that, at Zion, Illinois, on the shores of Lake Michigan, there might be about 90 hours per year of tower-produced fog at the highest frequency point located 1.5 to 2.5 miles north of the towers as compared with the present 160 to 260 hours per year of natural fog. Maximum occurrence for tower-produced fog would be between 3 a.m. and 9 a.m. in the winter season. With winter temperatures often below freezing, icing would be likely to accompany the fog. Aynsley [7] indicates that humidity increases can be found many miles downwind of cooling towers.

It must be pointed out that cooling towers should have quite a different effect on the atmosphere than large land application systems. While the volume of water evaporated may be similar, the great amounts of heat available from the towers, leading to possible cloud and thunderstorm development, would not be present with land application systems. Higher humidities certainly will occur downwind of land application systems but since the moisture source is much larger, the humidities will probably not be as high and will exist over a wider but shallower band. Some icing might accompany the operation of the system during below-freezing conditions but since these conditions usually dictate storage of effluent, the opportunities for icing downwind of the system are greatly restricted. This is not the case with cooling towers.

Precipitation Influences of Large Lake Areas

McDonald [64] has well illustrated the relatively negligible effect of large water bodies on surrounding climates by calculating the influence of "Lake Fallacy," an imaginary lake 380 miles long and 50 miles wide stretching across the southern border of Arizona. This lake would be slightly larger than the combined areas of Lake Erie and Lake Ontario. McDonald calculates that such a lake would be necessary if one wished to augment the present July water vapor flux into the state of Arizona of some 2 million acre-feet per day by just 10 percent. He carefully points out, however, that increasing the water vapor influx by 10 percent is no guarantee that precipitation will increase by 10 percent because the average residence time of water vapor in the air is about 10 days. Using normal wind speeds and trajectories, it is clear that most of the added water vapor will be far from Arizona before it falls again as precipitation. McDonald suggests that the only way to create more local precipitation would be to pile up all the dirt excavated in creating Lake Fallacy to form a 10,000-foot mountain just downwind of the lake. Orographic cooling of the air (whether augmented by additional moisture evaporated from the lake or not) would then increase the precipitation locally. As a final argument, McDonald points to the very dry conditions existing around the Caspian Sea, evaporating some 400 to 500 million acre-feet annually. Only on the south where mountains squeeze moisture out of the air is the precipitation appreciable. Around the rest of the lake, arid and semiarid conditions point up the very small influence that such a large wet surface has on local atmospheric conditions.

Conclusions

The climatic changes that accompany irrigation enterprises are relatively local in magnitude. Air moving over an irrigated tract will rapidly pick up moisture. Within the first few hundred feet in all but the most arid region, the air will have essentially reached equilibrium. Once the air has left the moistened area, turbulent mixing will rapidly reduce the moisture content to its original low value.

SECTION VIII

COST EVALUATION

Cost evaluations for irrigation, overland flow, and infiltration-percolation will be discussed in this section. Costs of existing systems will be reported, and typical costs will be presented for a hypothetical 1-mgd system operating under each of the three approaches.

Costs reported in the literature are scarce and are given in various units. Capital costs will be presented, as often as possible, in dollars per mgd or dollars per acre. Where amortization of capital costs is possible, the results will be given in cents per thousand gallons of treated wastewater. Operating and maintenance costs will be given in cents per thousand gallons of treated wastewater whenever possible.

IRRIGATION

The capital and operating costs for irrigation will be evaluated in the following discussion. Also included is a discussion of the economic benefits arising out of irrigation.

Capital Costs

Capital costs for irrigation have been grouped into costs for land, pretreatment, and for transmission and distribution.

Land - Costs for land can be a large part of the initial capital cost. The flow and loading rate to be used will determine the land requirements. The cost of land for 16 recently designed and completed systems in Michigan ranged from \$225 to \$500 per acre [139]. The area required for these systems varied from 38.5 to 400 acres.

A survey taken by the APWA of 69 municipal sites in the United States showed that land costs ranged from \$5 per acre in 1947 in Washington to $5,000 per acre in 1965 in California. The median was about $500 per acre. In some cases the land was already owned by the municipality, so there was no charge for land made to the project. For the six irrigation sites visited for this study, land costs ranged from $100 per acre at Woodland, California, to $800 per acre for the Idaho Supreme Company at Firth, Idaho.

One of the previous problems with purchasing land was that there was no federal funding to help pay for it. Land costs were not eligible for grants; consequently, the cost had to be borne by a bond issue or similar funding. Under the new federal law, land costs are eligible for grants if the land is an integral part of the treatment system; if it is not, they will have to be paid for wholly by the operating municipality or industry. It may also be possible to lease land as an alternative to outright purchase, or to contract with local farmers or agricultural enterprises.

Pretreatment - Pretreatment costs vary considerably with the geographical area and the type of treatment. Smith [114] investigated costs in June 1967 for conventional and advanced treatment of wastewater. At that time, the national average ENRCC (Engineering News-Record Construction Cost) index was 675, and the STPCC (Sewage Treatment Plant Construction Cost) index was 119.1 Because the STPCC index better reflects the changing costs of treatment, it was chosen to update Smith's costs to 1973 conditions. Pretreatment costs for a 1-mgd plant have been updated to an STPCC index of 192.8 for January 1973 and are listed on Table 26. Construction costs have been amortized over 25 years at 7 percent interest.

Capital costs for screening of industrial wastewater for canneries are reported to be 0.14 to 0.29¢ per case of product [61]. Vibrating 40-mesh screens, conveyors, and hoppers in 1968 cost $19,000 per mgd for a 0.5-mgd installation, $12,300 per mgd for a 1-mgd installation, and $8,700 per mgd for a 4-mgd installation [135]. For a 10-year life at 7 percent interest and 250 days of operation, this cost amounts to 0.7¢/1,000 gal. for a 1-mgd flow.

Operating costs for screening will range from 2.0¢/1,000 gal. for a 1-mgd plant to 1.7¢/1,000 gal. for a 4-mgd plant [135].

Transmission and Distribution - The transmission and distribution system can be a complicated pump and piping arrangement or a simple open ditch with gravity flow. The

Table 26. Typical Costs of Pretreatment for 1-mgd Plants [114] January 1973 STPCC Index 192.8

Type of treatment	Capital cost, ¢/1,000 gal.[a]	Operating cost, ¢/1,000 gal.[b]	Total cost, ¢/1,000 gal.
Screening[c]	0.7	2.0	2.7
Primary	13.3	7.3	20.6
Secondary			
Activated sludge	20.9	13.7	34.6
Trickling filter	18.9	9.7	28.6
Physical-chemical[d]	33.8	16.2	50.0
Chlorination	0.6	1.5	2.1

a. Capital cost at STPCC index 192.8, amortized over 25 years at 7 percent interest.

b. Operating costs updated by $\frac{192.8}{119.1}$ = 1.62 times reported costs.

c. From reference [135] for vibrating 40-mesh screens.

d. Physical-chemical treatment costs determined by adding coagulation-sedimentation (lime and ferrous sulfate) costs to granular carbon adsoprtion costs.

topography and existing treatment facilities will dictate which method is most feasible.

For spray irrigation, the cost of transmission and distribution systems is more than for other forms of irrigation, because such systems must cover the entire field and are generally more sophisticated. The cost of spray irrigation for the 10 Michigan sites ranges from $1,000 per acre for an 8-acre site to $5,000 per acre for a 16-acre site [139]. Other costs varied from $200 to $2,300 per acre for industrial systems (canneries) [61].

Nesbitt and Allender [2, 87] reported amortized spray irrigation capital costs in 1967 dollars for a 1-mgd system at 10¢/1,000 gal. Key assumptions included: (1) secondary quality effluent, (2) 40 days' equalizing storage, (3) solid set sprinklers at 98-foot by 70-foot settings, and (4) transmission for 1 mile by pumping against 200 feet of head. The capital costs were amortized over 20 years at 6 percent interest. Discounting the land cost of $140 per acre, the estimated capital cost for transmission and distribution amounted to $2,700 per acre.

For spray sites visited the costs were: $800 per acre (in 1968) for the solid set system at Idaho Supreme; $1,500 per acre (in 1966) for golf course irrigation at Moulton-Niguel in California; and $140 per acre (in 1968) for a center pivot rig at Portales, New Mexico.

The cost of increased pumping head must be compared with the cost of different pipe sizes to obtain the most economical solution for the design flow. The costs of pumping stations versus flow for an ENRCC index of 1860 (March 1973) are shown on Figure 12. These costs are general in nature; local manufacturers should be contacted for more exact costs.

The cost of piping for transmission to the site will vary with the amount of pipe ordered, type of pipe, and shipping distance. As with the pump costs, local manufacturers should be contacted for price information.

Distribution piping costs versus effective distribution diameter for square, rectangular, and triangular settings are shown on Figure 13. Effective distribution diameter is the wetted diameter for a single sprinkler. Again, these costs are for 1967 in Pennsylvania, and local contacts should be made for pipe prices. Sprinkler heads vary from $3 to $15 each, depending on the type and complexity.

Reported costs for construction of ridge and furrow systems and flood irrigation systems are sparse. They are generally much lower than spray irrigation costs except when extensive earthwork is involved. At Westby, Wisconsin, a ridge and furrow system was carved into a 5 percent slope using four terraces. The cost, including earthwork, piping, and pumping, was about $2,500 per acre. On the other hand, when the flow is by gravity, the costs can be very low. Reported costs for the ridge and furrow system at Mount Vernon Sanitary District, California, in 1956 were $75 per acre, which included leveling, preparation, and fertilizing of the 1,000 acres [78]. Schraufnagel [105] reported

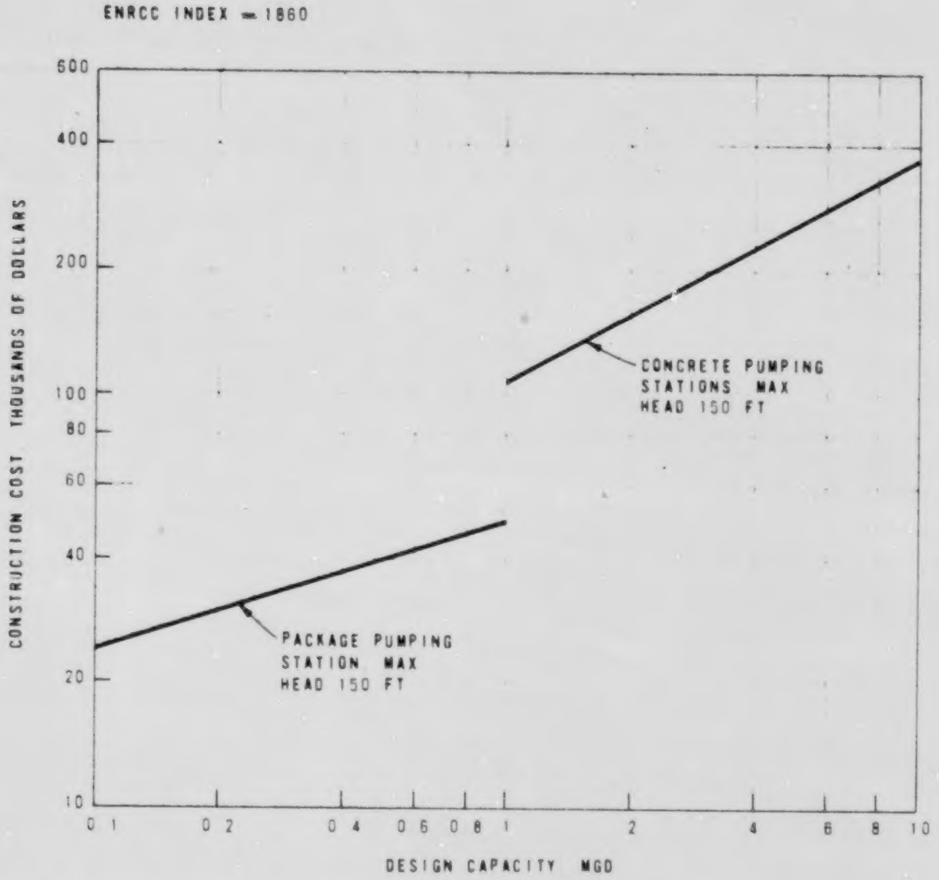


FIGURE 12
CONSTRUCTION COST OF SEWAGE PUMPING STATIONS

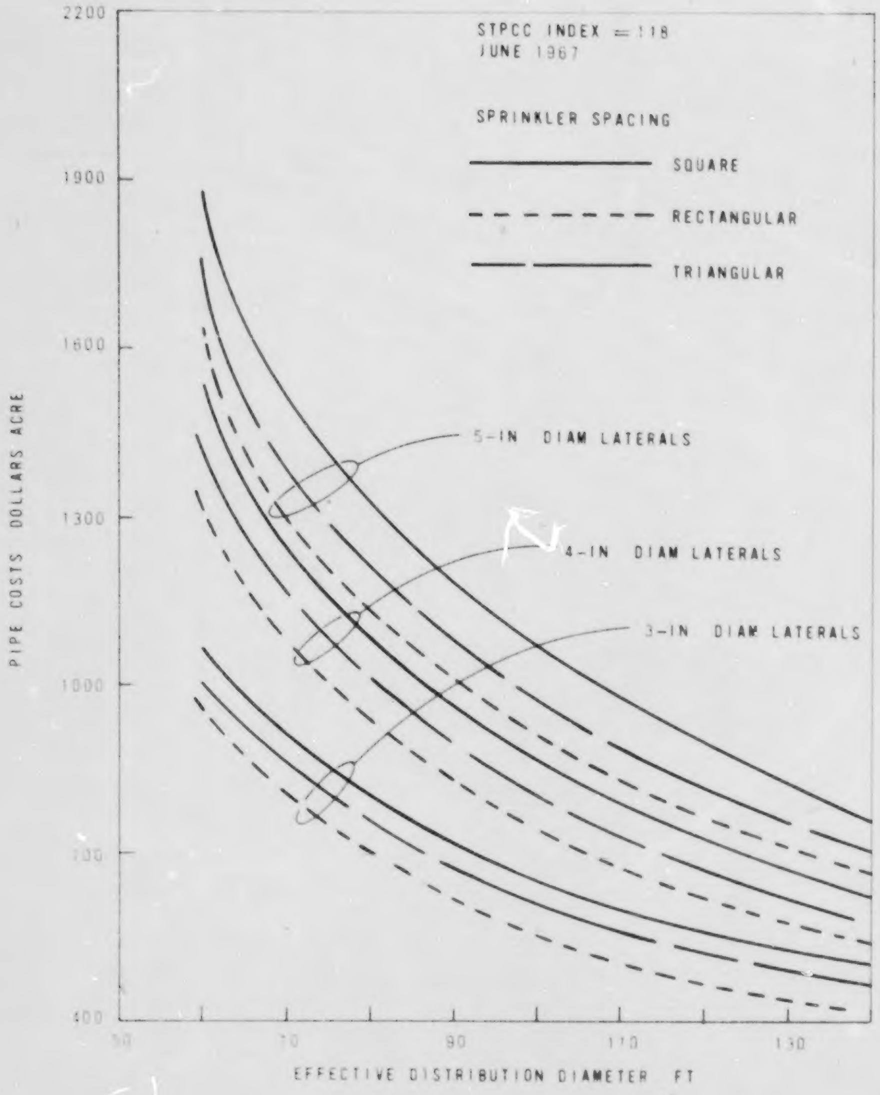


FIGURE 13
DISTRIBUTION PIPE COSTS FOR SPRAY IRRIGATION [2]

ridge and furrow costs of $300 per acre for a Minnesota creamery in 1950, and $2,000 per acre for a Wisconsin creamery in 1954.

Operation and Maintenance Costs

Costs for operating and maintaining irrigation systems depend upon the type and size of the system and the geographical location. Operating and maintenance costs are evaluated here for spray, ridge and furrow, and flood irrigation systems. Annual budgets for several cities and industries, gathered in part by APWA, are listed in Table 27. Annual budgets include operating and maintenance costs for pretreatment as well as irrigation. The higher costs for industries are due, in part, to the seasonal nature of the operation and also to the fact that all industries listed in Table 27 use spray irrigation. For example, the Green Giant Company operation at Montgomery, Minnesota, lasts 100 days, and many other canneries operate only 60 days per year.

Spray Irrigation – For municipalities, operating and maintenance costs may range from 2.7 to 11.6¢/1,000 gal., as shown in Table 27. Included are costs for labor, replacement materials, and power.

For industries the literature offers a long and varied list of costs, reported in various units such as cents per case. In Minnesota the operating and maintenance cost for a spray irrigation system in 1953 was 0.6¢ per case [86]. This waste was from the canning of peas and corn with a waste flow of 65 gal. per case. Converted to the more general unit of cents per 1,000 gallons, the cost in 1951 was 9.3¢/1,000 gal. Because canning waste flows vary tremendously within the industry, it is difficult to convert the other reported costs in the 1950s which ranged from 1 to 5¢ per case for spray irrigation [61]. For pulp and paper waste flows, Parsons [92] estimated spray irrigation costs at 5¢/1,000 gal. in 1967. For the U.S. Gypsum Company at Pilot Rock, Oregon (see Table 27), pulp and paper wastes are spray irrigated at a cost of 8.8¢/1,000 gal.

Ridge and Furrow Irrigation – The Beardmore tannery at Acton, Ontario, conducted a comparison of costs for spray versus ridge and furrow irrigation in 1958. Operating costs for ridge and furrow were 12.7¢/1,000 gal. while those for spray irrigation were 7.7¢/1,000 gal [105]. In 1953, before converting from ridge and furrow to spray irrigation, the Green Giant Company cannery at Montgomery, Minnesota, analyzed the costs. Ridge and furrow costs were

Table 27. Annual Costs of Operation and Maintenance for Municipal and Industrial Irrigation Systems

Location	Flow rate, mgd	Pre-treatment[a]	Type of application	Annual budget, $	Annual cost, ¢/1,000 gal.
Municipalities					
Oceanside, California	1.5	S	Spraying	63,700	11.6
St. Charles, Maryland	0.5	O	Spraying	15,500	8.7
Pleasanton, California	1.3	S	Spraying	35,000	7.4
Colorado Springs, Colorado	5.5	T	Spraying	137,700	6.9
Ephrata, Washington	0.4	O	Spraying	5,000	6.8
Bakersfield, California	12.3	P	Ridge and furrow	216,000	4.8
Ely, Nevada	1.5	S	Flooding	22,000	4.0
San Angelo, Texas	5.0	P	Flooding	54,000	3.0
Calabasas, California	3.0	S	Spraying	30,000	2.7
Industries					
Green Giant Company Montgomery, Minnesota	1.2	Sc	Spraying	28,000	23.9
Celotex Corporation L'Anse, Michigan	0.6	P	Spraying	25,000	22.9
Western Farmers Association, Aberdeen, Idaho	0.5	P	Spraying	25,000	21.4
Celotex Corporation Lagro, Indiana	0.2	P	Spraying	6,000	9.1
U.S. Gypsum Company Pilot Rock, Oregon	1.2	--	Spraying	28,500	8.8
Stokely Van Camp Fairmont, Minnesota	1.5	Sc	Spraying	23,000	7.3

a. S = secondary; O = oxidation ponds; T = tertiary; P = primary; Sc = screening.

1¢ per case or 22.2¢/1,000 gal. on the basis of 45 gal./case.

A citrus product company in California built a 0.7-mgd ridge and furrow irrigation system, modified by "back-furrows" or perpendicular intersecting furrows, covering 240 acres. The annual cost in 1950 was $15,300 for labor and supplies for the farming operation, $9,000 for labor and supplies for the irrigation operation, $14,000 for depreciation of equipment, sewer maintenance and improvement, and $2,100 for consulting services. Irrigation with wastewater was done only prior to the growing season; well water was used during the growing season. The crop produced an income of $20,000 to help offset the costs [62].

For municipalities, Bakersfield, California, has an operating cost of 4.8¢/1,000 gal. for the primary treatment plant and the ridge and furrow system. The City leases 2,400 acres for irrigation of pasture, cotton, barley, corn, wheat, and alfalfa.

Flood Irrigation – Costs for flood irrigation should be about the same as for ridge and furrow irrigation. The operation of the two types of systems is similar in nature, and the maintenance is approximately the same.

Border check irrigation as practiced at Abilene, Texas, and Woodland, California, is relatively inexpensive. Although both cities lease their land to individual farmers for $12 per acre and $23 per acre, respectively, the operating costs for secondary treatment at Abilene are 7¢/1,000 gal. for 9.0 mgd and for oxidation ponds at Woodland, 4.2¢/1,000 gal. for 8.7 mgd.

Economic Benefits

For irrigation, a municipality or industry may derive direct economic benefits in several ways. For overland flow the benefits are derived largely from the sale of hay, but there may be some secondary benefit from the sale of recovered treated water. For infiltration-percolation, direct benefits usually come from the sale of recovered water.

Cities such as Woodland, California, Abilene, Texas, Pomona, California, and San Angelo, Texas, derive direct benefits in different ways. At Woodland, the city's land is leased for $23 per acre for summer irrigation, and in addition, a duck club pays about $6 per acre for the same land for late fall duck hunting privileges. At Abilene, city land is leased for $12 per acre, and additional effluent is provided to adjacent farms in place of cash payments as a result of a lawsuit settlement (see Appendix A). Pomona purchases treated wastewater from the Los Angeles County Sanitation Districts at $7 per acre-foot and sells it to various users at $5 to $22 per acre-foot. At San Angelo, four city employees operate the 750-acre city farm at a profit of $30 per acre. The operating costs for 1972 of $54,000 were offset by an annual return of $76,700.

OVERLAND FLOW

An overland flow system is similar to a spray irrigation system in that sprinklers are used to distribute the water. The main differences are that the land is sloping, the water runs off, and the crop is not always harvested. The capital and operating costs are evaluated in the following discussion.

Capital Costs

Capital cost items include land, earthwork, pretreatment, transmission, distribution, and collection.

Land - Land costs for an overland flow site could be cheaper because sloping land can be utilized. As mentioned under "Irrigation," the cost of land is strictly dependent on local conditions. Land slopes up to 12 percent have been used at Paris, Texas. Land costs for the 500-acre site at Paris varied from $50 to $600 per acre [21].

Earthwork - The amount of land grooming will vary from site to site. The land should have a uniform slope with no low spots for ponding. Collection ditches can be placed traversing the sloping land to carry off the surface water. Construction costs for Paris, Texas, were $1,006 per acre: $362 for clearing land, $108 for grass cover, $348 for the piping system, and $188 for miscellaneous work [21]. About one-half of the construction cost of the Hunt-Wesson system at Davis, California, was for earthwork. This amounted to approximately $1,500 per acre because the land was nearly flat prior to construction.

Pretreatment - The pretreatment required by the overland flow system at Paris, Texas, consists of fine screening and grease removal. The sprinkler system must be protected from clogging, or maintenance costs will increase.

Transmission and Distribution - The requirement for sloping ground with sprinklers necessitates pumping of the effluent. The piping for the overland flow system will be basically the same as for a spray irrigation site. Figure 12 may be consulted for cost data.

The piping system for Paris, Texas, cost $348 per acre to install [21]. The cost for piping at the Hunt-Wesson plant at Davis, California, was about 40 percent of the total construction cost.

Collection - The collection of surface runoff should be included in the earthwork costs. Ditches are constructed across the slope to intercept the surface flow. For sites that require little earthwork, the ditches will be a major part of the earthwork cost. For the Hunt-Wesson plant at Davis, the collection ditches were about 10 percent of the earthwork cost, or about $50,000 for 320 acres.

Operation and Maintenance Costs

Data on overland flow facilities are scarce because of the limited number of overland flow sites in operation. At the Paris, Texas, site of the Campbell Soup Company plant, the annual operational cost is 5¢/1,000 gal. The operational cost is reduced slightly by the income of 0.4¢/1,000 gal. from crops produced on the site. For Hunt-Wesson at Davis, California, the annual cost is approximately 5 to 10¢/1,000 gal.

Management – Management costs will vary with the size of the operation. A small site may require only part-time labor, while a larger site, such as at Hunt-Wesson, Davis, will require a full-time operator and maintenance man plus part-time help. Salaries for operators typically range from $3.50 to $7.00 per hour. The amount charged for part-time operation will be in direct relation to the actual amount of time spent at the site. Labor costs may amount to about 50 percent of the annual operating cost.

Additional costs will be laboratory fees for analyses made on water samples. The extent of the monitoring program will dictate the laboratory fees.

Maintenance – Sprinklers and pumps will require routine maintenance, and the ground must be checked for erosion. Hay, which requires cutting, is grown at the Paris, Texas, site. In 1968, three cuttings were made and the hay was sold to local cattlemen [21].

Typical costs for maintenance may range from 1 to 2¢/1,000 gal. This covers routine maintenance of pumps, distribution systems, and ground or field cleanup. Costs for replacement of worn out or broken items of equipment will be in addition to those for daily maintenance.

Power – Power costs for sites will be set by the rate obtained from local power companies. Better rates can be obtained for an industrial or municipal site than for a small, private operation.

The power costs for a spray distribution system with pumps supplying the pressure will run 10 percent to 25 percent of the total annual cost. The cost will vary with the flow quantity and discharge pressure required. Costs reported in the literature vary from 1.3 to 2.0¢/hp-hr of operation.

The approximate cost of power can be calculated from the pump efficiency, pump horsepower, and local power rates. Additional power requirements for lighting and other needs will be small in comparison with those for pumping.

INFILTRATION-PERCOLATION

Capital and operating costs for infiltration-percolation systems will generally be less than those for irrigation or overland flow because smaller areas of land are used and distribution is usually by gravity flow. For high rate systems, however, pretreatment needs are substantially greater for infiltration-percolation than for irrigation or overland flow.

Capital Costs

Capital cost items include land, earthwork, pretreatment, transmission, distribution, and recovery. Pretreatment and recovery will generally involve the largest costs.

Land - Land for infiltration-percolation sites is generally in sand and gravel areas, in or near river flood plains. The largest area found in use was the 40 acres at Hemet, California. At Westby, Wisconsin, the land cost $750 per acre in 1958. At Phoenix, Arizona, land for expansion of the 2-acre Flushing Meadows project might cost as much as $2,000 per acre.

Earthwork - Earthwork required at an infiltration-percolation site will include construction of the basins and grading of the beds. Some sites have placed 6 inches of pea gravel over the beds to retard plant growth, and this will cost an additional amount to spread. The dikes generally involve the bulk of the earthwork.

The earthwork costs for the basins at Flushing Meadows were about $1,500 per basin. The total construction costs per basin were about $1,800. It should be noted that these were experimental basins and therefore costs were relatively high.

Pretreatment - The wastewater spread on an infiltration basin should be fairly free of solids that would clog the surface and reduce the infiltration rate. At Flushing Meadows a sedimentation basin was constructed to capture solids present in the activated sludge effluent.

At Whittier Narrows, an activated sludge treatment plant was built to pretreat the wastewater. Costs of conventional treatment are listed in Table 26.

Treatment and Distribution – At Flushing Meadows, Arizona, and Whittier Narrows, California, transmission and distribution are by gravity flow. At Santee, California, the wastewater is pumped to the site and distributed by gravity flow.

Transmission pipe costs can be taken from Figure 12. The distribution canals for Flushing Meadows cost $98,000 but were concrete lined. The lining accounts for 98 percent of the cost of the canals. The cost of the transmission and distribution systems was about 50 percent of the construction cost.

Recovery – A recovery system may or may not be a part of an infiltration-percolation site. The groundwater recharge systems at Long Island, New York, and at Hemet, California, are used to create a hydraulic barrier to salt water intrusion.

Sites at Whittier Narrows and Santee have recovery systems to reclaim the water. The recovery systems consist of wells which pump a mixture of reclaimed water and groundwater to where it is used. At Santee the water is used for recreation facilities; at Whittier Narrows, the reclaimed water is sold to groundwater users.

The cost of wells is shown on Figure 14. This is a generalized graph and not an illustration of absolute figures. The cost of wells planned at Flushing Meadows is $35 per foot. Eight are to be constructed 200 feet deep for a cost of $56,000. Pumps for the wells are estimated to be $17,500 each, or $140,000. The total cost is estimated to be $196,000 [19].

A recovery system is not necessary for the recharge facility. Existing privately owned wells nearby could benefit from the recharge operation and pay for the water pumped.

Operation and Maintenance Costs

Operation and maintenance costs for infiltration-percolation systems consist of costs for labor, maintenance, and power. At Flushing Meadows, Arizona, the operating cost is 2.4¢/1,000 gal. while at Whittier Narrows, California, it is 2.7¢/1,000 gal.

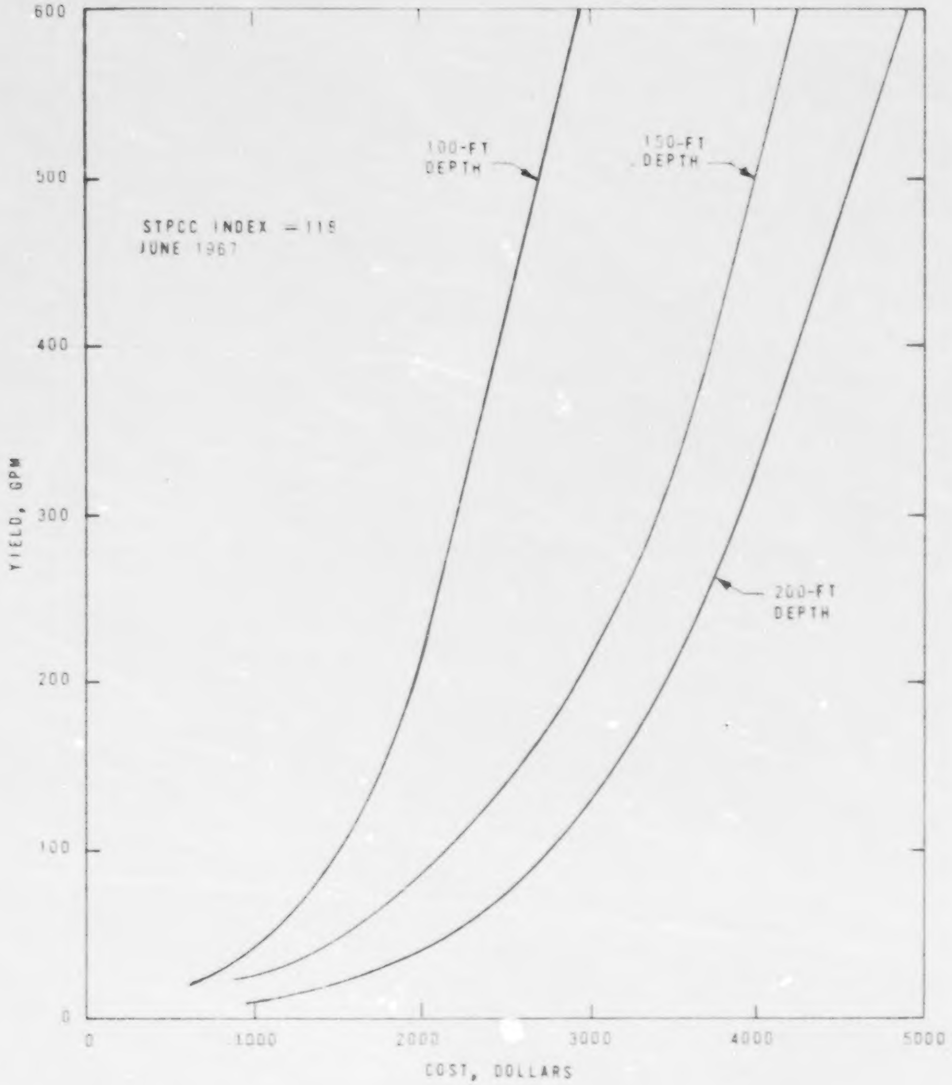


FIGURE 14
COSTS FOR RECOVERY WELLS [2]

Labor requirements at Flushing Meadows are 80 man-hours per week for an 0.5-mgd system, but again this reflects the research that was being conducted. At Westby, Wisconsin, with a flow rate of 0.2 mgd, labor is less than 20 man-hours per week.

Simpson Lee Paper Company operates two pulp and paper waste disposal systems by infiltration-percolation. At Kalamazoo, Michigan, 7 in./day is applied by spraying and at Vicksburg, Michigan, 1 in./day is applied by spraying. At Kalamazoo the operating cost is 2.6¢/1,000 gal., and at Vicksburg the cost is 2.9¢/1,000 gal. Pretreatment costs for primary settling are included in both costs.

Hunt-Wesson Foods, Inc., produces 3.0 mgd of tomato wastewater at Bridgeton, New Jersey, and disposes of this wastewater, after screening, by spraying at a rate of 19 in./wk. The operating cost over 12 months is 3.7¢/1,000 gal.

COST COMPARISON FOR HYPOTHETICAL 1-MGD SYSTEMS

Hypothetical 1-mgd systems for spray irrigation, overland flow, and infiltration-percolation were assembled so that their capital and operating costs could be compared. All three systems were assumed to operate on a continuous basis without storage. Typical costs were assigned for each component of the system, and the totals are shown in Table 28. Capital costs in cents per 1,000 gallons are 10.1 for spray irrigation, 9.5 for overland flow, and 5.3 for infiltration-percolation. Operating costs in cents per 1,000 gallons are estimated to be 9.6 for spray irrigation, 7.6 for overland flow, and 3.5 for infiltration-percolation.

Pretreatment

Costs for pretreatment have not been included in the cost buildup for several reasons. First, the extent of the need for pretreatment for irrigation and overland flow has not been firmly established. Irrigation with primary effluent has been successful; however, recent regulations may require secondary quality for irrigation. Screening and comminuting may be the minimum pretreatment required for overland flow, but this requires full-scale substantiation. High rate infiltration-percolation requires secondary quality, although moderate rates will function successfully with primary effluent. Second, the costs of conventional pretreatment have been delineated in Table 26, and these additional costs can be added to actual land application costs for any degree of pretreatment.

Table 28. Comparison of Capital and Operating Costs for 1-mgd Spray Irrigation, Overland Flow, and Infiltration-Percolation Systems[a]

Cost item	Spray irrigation	Overland flow	Infiltration-percolation
Liquid loading rate, in./wk	2.5	4.0	60.0
Land used, acres	103	64	--
Land required, acres[b]	124	77	5
Capital costs			
Land @ $500/acre	$ 62,000	$ 38,500	$ 2,500
Earthwork	10,300	64,000	10,000
Pumping station	50,000	50,000	--
Transmission	132,000	132,000	132,000
Distribution	144,000	64,000	5,000
Collection	--	6,000	30,000
Total capital costs	$398,300	$354,500	$179,500
Capital cost per purchased acre	$3,200	$4,600	$35,800
Amortized cost[c]	$37,000	$34,700	$19,500
Capital cost, ¢/1,000 gal.	10.1	9.5	5.3
Operating costs			
Labor	$10,000	$10,000	$ 7,500
Maintenance	19,400	12,000	3,500
Power	5,800	5,800	1,800
Total operating costs	$35,200	$27,800	$12,800
Operating cost, ¢/1,000 gal.	9.6	7.6	3.5
Total cost, ¢/1,000 gal.	19.7	17.1	8.8

a. Estimated for 1973 dollars, ENRCC index 1860 and STPCC index 192.

b. 20 percent additional land purchased for buffer zones and additional capacity.

c. 15-year life for capital items, excluding land; interest rate 7 percent.

Land

The land needed for each system was calculated from the 1-mgd flow rate and the liquid loading rate. Typical loading rates were chosen, and the resultant land area was increased by 20 percent for buffer zones for spray irrigation and overland flow, or excess capacity for infiltration-percolation. A land price of $500 per acre was chosen as typical.

Earthwork

For earthwork costs it was assumed that some land preparation was required for spray irrigation at $100 per acre. For overland flow, terracing required major earthwork (assuming previously level land) at $1,000 per acre. Also included were costs for preparation, planting, and fertilizing. For infiltration-percolation basins, ten 1/2-acre basins were required at $1,000 per basin.

Pumping Stations

From Figure 12, a 1-mgd package pumping station would cost $50,000 for both the spray irrigation and overland flow cases. It was assumed that the wastewater could be transmitted to the site by gravity flow; therefore, no pumping stations for distribution were included for infiltration-percolation.

Transmission

The hypothetical site was located 1 mile from the treatment plant or wastewater source. Transmission was by gravity flow through a 24-inch pipe, installed at a cost of $25 per foot. It should be noted that the same plot of land was not being considered for each approach.

Distribution

For spray irrigation use was made of Figure 13. An effective diameter of 100 feet for square spacing was chosen using 4-inch laterals. The resultant cost per acre of $850 was increased from STPCC index 118 to 192, and the cost per acre in 1973 dollars is $1,400.

For overland flow, the distribution pattern was not square so a typical cost of $1,000 per acre was chosen. Similarly, a cost of $1,000 per acre was assigned for distribution among the 10 basins for infiltration-percolation.

Collection

For overland flow, a series of collection ditches were required at a cost of approximately 10 percent of the distribution costs, or $6,000. For infiltration-percolation, 3 wells for recovery were required. The wells had a capacity of 600 gpm each and, at 100-foot depths, cost $3,000 each for 1967 conditions. Updating the well costs to 1973 dollars and adding $15,000 for recovery pumps, the cost for collection became $30,000.

Operation and Maintenance

Labor requirements were expected to be one man, full-time, for spray irrigation and overland flow. A single man operating three-fourths of the time was necessary for infiltration-percolation.

Maintenance costs were calculated as 10 percent of the capital costs of pumping stations, distribution, and collection. Power costs were variable, but were expected to be 2¢ per hp-hr.

SECTION IX

LAND APPLICATION POTENTIAL

Many benefits as well as limitations involved in land application have been discussed in this report. In this section the intent is to place both limitations and positive aspects of land application in perspective and to attempt to analyze the future potential of the various methods. The first part of the discussion deals with municipal wastewater; the second part deals with industrial wastewater.

MUNICIPAL WASTEWATER

Land application of municipal wastewater in this country has been done mainly by irrigation, to a lesser extent by infiltration-percolation, and not at all by overland flow. The limitations and benefits of each approach are different and will be discussed separately.

In comparing the three approaches to land application it is helpful to define the objectives to be achieved with treated wastewater and to observe the response of each approach in realizing those objectives. In Table 29 a list of objectives has been assembled and the ability of each approach to realize those objectives is tabulated. As can be seen, each approach has several potentialities as well as limitations. In addition to considerations of management objectives, an analysis of land application must include considerations of the Federal Water Pollution Control Act Amendments of 1972.

Federal Amendments of 1972

Land application was given a substantial role in the Federal Amendments of 1972 to implement the "national goal that discharge of pollutants into navigable waters be eliminated by 1985." Section 201(b) of the Act stipulates that:

> (b) Waste treatment management plans and practices shall provide for the application of

Table 29. Comparison of Irrigation, Overland Flow, and Infiltration-Percolation for Municipal Wastewater

	Type of approach		
Objective	Irrigation	Overland flow	Infiltration-percolation
Use as a treatment process with a recovery of renovated water	Impractical	50 to 60% recovery	Up to 90% recovery
Use for treatment beyond secondary:			
1. For BOD and suspended solids removal	90-99%	90-99%	90-99%
2. For nitrogen removal	Up to 90%[a]	70-90%	0-80%
3. For phosphorus removal	80-99%	50-60%	70-95%
Use to grow crops for sale	Excellent	Fair	Poor
Use as direct recycle to the land	Complete	Partial	Complete
Use to recharge groundwater	0-30%	0-10%	Up to 90%
Use in cold climates	Fair[b]	--[c]	Excellent

a. Dependent upon crop uptake.

b. Conflicting data--woods irrigation acceptable, cropland irrigation marginal.

c. Insufficient data.

> the best practicable waste treatment technology before any discharge into receiving waters, including reclaiming and recycling of water, and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution and shall provide for consideration of advanced waste treatment techniques.

Land application is emphasized in Section 201(d)(1) by the stipulation that:

> (d) The Administrator shall encourage waste treatment management which results in the construction of revenue producing facilities providing for —
>
> (1) the recycling of potential sewage pollutants through the production of agriculture, silviculture, or aquaculture products, or any combination thereof;

Thus, land application must be considered as an alternative to conventional and advanced wastewater treatment in the prevention of surface water pollution.

Irrigation

The benefits of irrigation are many: economic return on the sale of crops; saving of potable water supplies through exchange by irrigating landscapes, golf courses, parks, and highway medians with wastewater; fire protection by hillside spraying (especially in California [141]); and serving as a positive and reliable alternative to advanced waste treatment and/or surface water discharge. The latter benefit applies to most land application methods.

As shown in Section VIII, economic benefits from the sale of crops have been substantial in some cases. Operating costs are low due to the relative simplicity of operation.

Irrigation with municipal wastewater may be allied with the need for open space and green belts in urban and suburban areas. The Golden Gate Park wastewater reclamation plant in San Francisco, California, has been producing 1 mgd of water for this purpose for the last 40 years [70, 48, 73]. Irrigated lands have also been leased for recreational purposes such as duck hunting in the fall. In Section 201(f) of the 1972 Federal Amendments it is stipulated that "waste treatment management which combines open space and recreational considerations with such management" shall be encouraged.

Several limitations to irrigation have been mentioned in this report. The principal ones are the considerable land area required, its relatively high cost, and its relatively long distance away from large urban sources of wastewater. In climatic Zones A and B in moderate-sized cities near agricultural areas, the practice is quite feasible, and many cities have followed this approach. In climatic Zones C, D, and E the need for irrigation water is less and agricultural land has considerable value without irrigation; therefore, the practice requires other motivations. At Muskegon, Michigan, where nearly 10,000 acres will be irrigated, the need was for an economic and feasible alternative to surface water disposal [34].

Limitations to spray irrigation for health reasons are less severe. Adequately disinfected wastewater should pose no danger to health when it is sprayed. Aerosols for spraying should be kept from traveling as heavy mist outside of the irrigation tract by rows of trees or buffer zones. Any aerosolizing of inadequately disinfected municipal wastewater, be it in an activated sludge plant, a river outfall, or in a spray field, produces some risk to human health, and these risks should all be minimized. Sprinklers that spray downward or horizontally, especially with low nozzle pressure, adequate disinfection, and buffer zones all function to increase the safeguards.

Overland Flow

Overland flow is subject to the same types of limitations as irrigation, but it can be done with a relatively impermeable soil and a gently sloping terrain. These latter two factors may combine to yield a land site of moderate cost. In general, suitable sites will be as difficult to find within economic transmission distances of cities as they are for irrigation.

Overland flow has considerable potential for treatment of municipal wastewater. At Ada, Oklahoma, comminuted municipal wastewater has been sprayed at low pressures in an experimental system at a loading rate of about 4 in./wk. The results show an effluent of a quality approaching that from tertiary treatment. In addition to a relatively low construction cost, the system produces no sludge, which is an aspect with great appeal.

Operating costs are considerably lower than for conventional plus advanced waste treatment because of the relative simplicity of operation. Further research and development of this highly promising approach is required in the area of phosphorus removal, loading rates, and applicability to cold climates.

Overland flow has the advantages of avoiding groundwater degradation, of providing economic return through the growth and sale of hay, and providing a high quality effluent suitable for many additional reuse applications. As indicated in Table 29, it cannot be used as a complete direct recycle of wastewater to the land. However, the runoff will be of high quality and can be directly recycled by any other land application approach.

Infiltration-Percolation

Benefits from infiltration-percolation of municipal wastewater include (1) an economic alternative to surface water discharge, (2) a treatment system with nearly complete recovery of renovated water possible, and (3) a method of repelling salt water intrusion into aquifers. The high rate systems pioneered in the southwest have the further benefit of requiring very little land area.

The major limitations of the process are in connection with groundwater effects. The fact that influent nitrogen is converted to the nitrate form, which is leached to the groundwater, is of major concern. If the groundwater zone becomes anaerobic, conversion of sulfates to hydrogen sulfide may also be a problem.

Nitrates can be a problem (1) if the groundwater is reused for potable supply, (2) if the groundwater is reused for recreation lakes, and (3) if the groundwater is reused for unrestricted irrigation.

These problems are (in the order mentioned) related to (1) causing methemoglobinemia in children, (2) eutrophication, and (3) overstimulation of crops, such as grapes, in which nitrate nitrogen concentrations above 30 mg/L are reported to cause abundant growths of foliage at the expense of fruit production.

At Flushing Meadows, Arizona, research and operational changes have been aimed at increasing the nitrogen removal of their high rate system. Further research needs to be conducted on this subject.

Less critical limitations include the following: (1) phosphorus retention in the soil matrix may be neither complete nor of long duration; (2) suitable soils must be highly permeable yet must contain enough fine particles to ensure adequate renovation; and (3) the groundwater aquifer receiving the water needs to be monitored and controlled for high rate systems to prevent groundwater degradation.

INDUSTRIAL WASTEWATER

The potential use of land application for industrial wastewaters is nearly as great as that for municipal wastewater. In addition to the food processing, pulp and paper, and dairy industries which have utilized land application extensively, such diverse industries as tanneries [91] and chemical plants [140] have used land application successfully. In general, for plants located in rural or semirural areas that produce wastewaters with mainly organic contents, land application offers great potential. For industries producing toxic or high inorganic content wastewaters, land application probably offers small promise. There are so many modifications and combinations of land application methods that could be used for any given industrial wastewater, that no sweeping limitations can be stated solely on the basis of a type of industry.

In general, industries are more able than municipalities to include new technology in their wastewater management plans, which partially explains their use of the overland flow approach. Industries have allowed the soil matrix to provide a greater amount of treatment than have municipalities and have tended to search out the limits of loading for soil systems. With this approach it is likely that new improvements or modifications to the common methods will continue to come from industries as well as from soil scientists and researchers.

SECTION X

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SECTION XII

GLOSSARY OF TERMS, ABBREVIATIONS, SYMBOLS, AND CONVERSION FACTORS

TERMS

Adsorption--A process in which soluble substances are attracted to and held at the surface of soil particles.

Advanced waste treatment--Additional treatment designed to reduce concentrations of selected constituents present in wastewater after secondary treatment.

Alkali soil--A soil with a high degree of alkalinity (pH of 8.5 or higher) or with a high exchangeable sodium content (15 percent or more of the exchange capacity), or both.

Application rates--The rates at which the liquid is dosed to the land, usually in in./hr.

Aquifer--A geologic formation or strata that contains water and transmits it from one point to another in quantities sufficient to permit economic development.

Border strip method--Application of water over the surface of the soil. Water is applied at the upper end of the long, relatively narrow strip.

Consumptive use--Synonymous with evapotranspiration.

Contour check method--Surface application by flooding. Dikes constructed at contour intervals to hold the water.

Conventional wastewater treatment--Reduction of pollutant concentrations in wastewater by physical, chemical, or biological means.

Drainability--Ability of the soil system to accept and transmit water by infiltration and percolation.

Effective precipitation--Precipitation that enters the soil and is useful for plant growth.

Evapotranspiration--The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporated from adjacent soil, snow, or intercepted precipitation in any specified time.

Field area--Total area of treatment for an overland flow system including the wetted area and runoff area.

Fixation--A combination of physical and chemical mechanisms in the soil that act to retain wastewater constituents within the soil, including adsorption, chemical precipitation, and ion exchange.

Flooding--A method of surface application of water which includes border strip, contour check, and spreading methods.

Grass filtration--See overland flow.

Groundwater--The body of water that is retained in the saturated zone which tends to move by hydraulic gradient to lower levels.

Groundwater table--The free surface elevation of the groundwater; this level will rise and fall with additions or withdrawals.

Infiltration--The entrance of applied water into the soil through the soil-water interface.

Infiltration-percolation--An approach to land application in which large volumes of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores.

Irrigation--Application of water to the land to meet the growth needs of plants.

Land application--The discharge of wastewater onto the soil for treatment or reuse.

Loading rates--The average amount of liquid or solids applied to the land over a fixed time period taking into account periodic resting.

Lysimeter--A device for measuring percolation and leaching losses from a column of soil. Also a device for collecting soil water in the field.

Micronutrient--A chemical element necessary in only small amounts (less than 1 mg/L) for microorganism and plant growth.

Mineralization--The conversion of an element from an organic form to an inorganic form as a result of microbial decomposition.

Overland flow--Wastewater treatment by spray-runoff (also known as "grass filtration") in which wastewater is sprayed onto gently sloping, relatively impermeable soil which has been planted to vegetation. Biological oxidation occurs as the wastewater flows over the ground and contacts the biota in the vegetative litter.

Pathogenic organisms--Microorganisms that can transmit diseases.

Percolation--The movement of water through the soil pores once it has passed the soil-water interface.

Phytotoxic--Toxic to plants.

Primary effluent--Wastewater that has been treated by screening and sedimentation.

Refractory organics--Organic materials not removed in secondary treatment.

Ridge and furrow method--The surface application of water to the land through formed furrows; wastewater flows down the furrows and plants may be grown on the ridges.

Saline soil--A nonalkali soil containing sufficient soluble salts to impair its productivity.

Secondary treatment--Treatment of wastewater by physical, chemical, or biological means such as trickling filters, activated sludge, or chemical precipitation and filtration.

Sewage farming--Originally involved the transporting of sewage to rural areas for land disposal. Later practice included reusing the water for irrigation and fertilization of crops.

Soil texture--The relative proportions of the various soil separates--sand, silt, and clay.

Soil water--That water present in the soil pores in an unsaturated zone above the groundwater table.

Spraying--Application of water to the land by means of stationary or moving sprinklers.

Spray-runoff--See overland flow.

Tilth--The physical condition of a soil as related to its ease of cultivation.

Transpiration--The net quantity of water absorbed through plant roots and transpired, plus that used directly in building plant tissue.

Viruses--Submicroscopic biological structures containing all the information necessary for their own reproduction.

Wetted area--Area within the spray diameter of the sprinklers.

ABBREVIATIONS

acre-ft--acre-foot

BOD --biochemical oxygen demand

BOD$_5$ --5-day BOD

bu --bushel

cm --centimeter

COD --chemical oxygen demand

deg C --degree Centigrade

deg F --degree Fahrenheit

diam --diameter

ENRCC --*Engineering News-Record* construction cost (index)

fps --feet per second

ft --foot

gad --gallons per acre per day

gal. --gallon

gpd --gallons per day

gpm --gallons per minute

hr --hour
hp-hr --horsepower-hour
in --inch
kw --kilowatt
lb --pound
m --meter
max --maximum
mgd --million gallons per day
mg/L --milligrams per liter
mi --mile
min --minute
ml --milliliter
mm --millimeter
mo --month
mph --miles per hour
MPN --most probable number
ppm --parts per million
psi --pounds per square inch
SAR --sodium adsorption ratio
sec --second
sq ft --square foot
SS --suspended solids
STPCC --sewage treatment plant construction cost (index)
TDS --total dissolved solids
wk --week
yr --year

SYMBOLS

B --boron

Ca --calcium

Cu --copper

K --potassium

Fe --iron

Mg --magnesium

Mn --manganese

N --nitrogen

Na --sodium

NH_3 --ammonia

NO_3 --nitrate

P --phosphorus

S --sulfur

Zn --zinc

> --greater than

< --less than

μ --micro

CONVERSION FACTORS

million gallons x 3.06 = acre-feet

acre-inch x 27,154 = gallons

mg/L x ft/yr x 2.7 = lb/acre/yr

SECTION XIII

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APPENDIX A

SITE VISIT SUMMARIES

Data from many existing sites were used in the preparation of this report. Visits were made to 9 selected sites in the United States and 1 in Canada. Data from 11 sites were collected during previous studies for specific clients. In addition, through cooperation with APWA, data from 63 cities and 19 industries were analyzed. Besides visiting sites APWA conducted a mail survey which netted information on an additional 78 cities and 36 industries.

SITES VISITED DURING STUDY

The 9 sites visited in the United States were: (1) Abilene, Texas; (2) Moulton-Niguel Water District, California; (3) Portales, New Mexico; (4) San Francisco, California; (5) Woodland, California; (6) Lake George, New York; (7) Phoenix, Arizona; (8) Westby, Wisconsin; and (9) Idaho Supreme Potato Company at Firth, Idaho. The first 5 sites involve irrigation with treated municipal wastewater; sites 6 through 8 involve infiltration-percolation with treated municipal wastewater; and site 9 involves spray irrigation of treated industrial wastewater. A spray irrigation site for industrial wastewater was also visited at Acton, Ontario. The descriptions of these visits are presented in this appendix in the sequence listed. Following the descriptions are the tabulations showing the actual data (Table 30).

Abilene, Texas

Effluent from a 9.0-mgd activated sludge plant is used for summer irrigation. Approximately 4.5 mgd is applied at a rate of about 3 in./wk by border strip irrigation.

History – In the early 1920s when the city of Abilene was quite small, the sewage disposal system was composed of a septic tank and subsurface drainage field. As the city grew, oxidation ponds were added to take care of excess liquids until 1926, when the system was moved to a new location about 5 miles northeast of the existing city. Six hundred and forty acres of land were purchased at that time, and more land was purchased in 1927, bringing the total acreage to 1,224 acres. Oxidation ponds and lagoons were constructed at the new location to provide some treatment. The effluent from the oxidation ponds was released to farmers in the immediate area to be used for irrigation purposes. This lagoon system remained in use until 1958. As the system was located on Lake Fort Phantom Hill watershed, the City could not qualify for State-approved water until the sewage irrigation system was moved. The City found a new location some 4 miles northeast of the old disposal area completely off the Phantom Hill watershed. Lake Fort Phantom Hill is Abilene's main source of water supply, having a capacity of 73,000 acre-feet.

In 1960 the City purchased 2,019 acres of land for the treatment plant and irrigation system. Features of that primary plant included grit removal, sedimentation, oxidation ponds, sludge digestion, and holding ponds. There are 40 acres of oxidation ponds and 375 acres of holding ponds with a capacity of 600 million gallons. The new sewer plant is located in Jones and Shackelford counties, in the Hamby Flat area, which is some of the best farming land in the Abilene area. Naturally, the thought of locating a treatment plant in that area was very unpopular with the farmers in the surrounding area. Actually, the Hamby area was about the only location that could be found that would be suitable for a disposal plant and still be located off the Abilene lake's watershed.

Lawsuits - The plant had been in operation only a short time when numerous complaints and protests were made by citizens from the immediate area about the creation of odors, mosquitoes, the seepage from the farm, and the creation of a general nuisance. From January 15, 1960, through June 12, 1963, 30 suits were filed against the City of Abilene, amounting to $1,500,000. The first five suits amounted to $164,800. These suits were tried by jury, and the plaintiffs were awarded $147,165. All of the suits were tried in out-of-county courts, but all of the suits were appealed to a higher court. While the lawsuits were going on, the City forces were busy correcting things that could be corrected, and improving where improvements were feasible. The years of 1960 and 1961 were very wet years, and there was a limited area (1,620 acres) on which to dispose of the sewage effluent. At times the whole farm was one large lake. Seepage from the farm was water-logging farmers in the surrounding areas. More than 4 million gallons of seepage water was entering Deadman Creek each day.

Deadman Creek flows around the farm and the farm is on the Deadman Creek watershed. Odors were bad in the area around the farm, because of the high load of BOD in the oxidation ponds and lagoons. The raw sewage entering the plant had an average BOD of 650 ppm in 1961. Also, because of the long distance the sewage had to travel to reach the plant, it became very septic. At that time, the City of Abilene did not have an Industrial Waste Ordinance, and a strong inorganic substance in the sewage was killing the algae growth in the oxidation ponds, which in turn increased the odors. Since the Industrial Waste Ordinance was passed in 1961, the BOD load has decreased from 650 ppm to about 250 ppm in 1964.

Many things were done to reduce odors and improve conditions in the farm area. The raw sewage was chlorinated about midway from town to the treatment plant. A perimeter ditch was dug around the farm to intercept sewage that was seeping from the farm and discharge it to Deadman Creek.

At the present time, all the lawsuits have been settled. The $1,500,000 in lawsuits were settled for $200,000. While the lawsuits were being tried the citizens of Abilene voted bonds to build a complete secondary sewage treatment plant. It is now in operation discharging 4.5 mgd in the summertime to Deadman Creek.

New Sewage Treatment Plant - In 1963, the City built a 12-mgd activated sludge plant. The aeration system is by submerged diffusers which are tapered from the head end to the discharge end of the plug flow tanks. The effluent is chlorinated with approximately 7 ppm to maintain a residual of 2 ppm in the effluent after 1 hour. The effluent can be discharged to Deadman Creek, the holding ponds, or to the irrigation system.

Irrigation System - The system consists of buried pipeline to the various user farms. In the settlement of several of the suits in the early 1960s, contracts were signed to supply 2,640 acre-feet of water annually to 5 different users. In additon, 1,554 acres of the original farm are leased to farmers and supplied with 24 acre-inches per acre annually. Mr. Martinez leases 1,400 acres for $17,000 per year or about $12 per acre. Land cost is about $300 per acre.

Since the average rainfall is 23 inches per year, the farmers only need irrigation water at certain times from May to September. A typical application rate is 6 in./day flooded on by border strip irrigation followed by 10 to 14 days of resting. The soil is a drainable loam underlain by pockets of sand and gravel but generally underlain by caliche (hardpan). The caliche and gravel are underlain by limestone. Groundwater reaching the pockets of sand and gravel will move laterally and emerge as seepage water. Crops grown include maize, cotton, wheat, and coastal bermuda grass. Cattle are grazed on the fields after harvesting of the maize. There are also three houses on the City's farm.

The treatment and disposal operations appear to be going smoothly. Mean annual effluent BOD is about 11 mg/L which is well below the discharge requirement of 20 mg/L. The operator indicated that his main problem in the effluent has been grease (discharged from packing houses). The cost for treatment of the wastewater prior to irrigation is 7¢/1,000 gal.

Moulton-Niguel Water District, California

This water district operates 3 wastewater reclamation plants in Orange County, in southern California. Reclaimed wastewater is used for golf course irrigation. All 3 plants have activated sludge treatment.

Plant No. 1A — This 400,000-gpd plant produces irrigation water for the 160-acre El Niguel Golf Course. The application rate is light at 1 in./wk, although the bermuda grass fairways need as much as 2 in./wk during the months of July through September. In November the flow from the plant is bypassed to the South Laguna sewage treatment plant as only the greens are irrigated over the winter months.

The soil of the golf course fairways is an adobe clay while the material for the greens is imported sandy loam. The course has a rolling terrain and a large proportion of the irrigated water runs off into small creeks and ultimately to Salt Creek and the ocean. The groundwater does not interfere with the operation.

After being treated by the activated sludge process, the effluent is discharged to 4 ponds in series. The first pond is aerated by three floating aerators while the other 3 ponds (1 acre each) are polishing ponds. The effluent is chlorinated and pumped to the golf course. Effluent requirements are: BOD and suspended solids, less than 30 mg/L; coliform organisms, MPN less than 2.2 per 100 ml; and incremental increase in TDS less than 300 mg/L.

The golf course management contracts for 350 acre-feet per year from Moulton-Niguel Water District at $1 per acre-foot.

It supplements this reclaimed water with MWD (Metropolitan Water District of Los Angeles) water which costs $52 per acre-foot. The annual cost of water to El Niguel Golf Course is $26,000.

Plant No. 2A – This 250,000-gpd plant discharges to 3 ponds presently used for percolation and evaporation. Future plans are to build recreational lakes and fill them with effluent.

Plant No. 3A – The largest of the 3 plants, this activated sludge plant has a capacity of 0.75 mgd, but normally produces 0.4 to 0.5 mgd for the irrigation of the 160-acre Mission Viejo Golf Course. In a manner similar to El Niguel Golf Course, Mission Viejo appropriates water from the Moulton-Niguel Water District at $1 acre-foot and from MWD at $52 per acre-foot. The annual cost of water for Mission Viejo is $14,000. This is nearly half of what El Niguel pays because the Moulton-Niguel Water District can supply the full 350 acre-feet per year to the golf course.

Secondary effluent is piped 0.9 mile under the San Diego Freeway to a holding pond. When effluent BOD exceeds 30 mg/L, the rapid sand filters are used as tertiary treatment prior to chlorination. A second chlorination station is at the effluent pumps from the holding pond. A combined residual of greater than 1.0 mg/L is maintained at the pumps so that a trace residual can be held at the farthest point in the spray system to prevent odors of sewage. In addition to maintaining a coliform count of less than 2.2 per 100 ml, a regulation restricts watering within 50 feet of public buildings with reclaimed water.

In the summer the golf course uses up to 1.25 mgd of water and in the winter as little as 0.1 mgd. When fairway irrigation is discontinued, the wastewater from the Moulton-Niguel plants goes to the South Laguna sewage treatment plant.

Portales, New Mexico

Effluent from a trickling filter plant is used to irrigate alfalfa and cotton. Spray, ridge and furrow, and border strip irrigation methods are used to apply the 1-mgd flow to the land.

History – Portales had a sewage farm in the 1930s. Regulations against irrigation with raw sewage forced the construction of an Imhoff tank in 1935. In 1942 a primary plant was built and upgraded with trickling filters in 1952.

In the 1950s the City's farm was converted to a sanitary landfill. A ditch was constructed several miles to a marshy area known as a "salt lake." A farmer along the route, Mr. Gonzales, began diverting summer flows for irrigation of cotton and alfalfa in about 1962. In 1968, Roger Patterson and Gordon Hatch built a 35 acre-foot holding pond, installed a pump, and began to spray irrigate 120 acres of alfalfa. The City does not own any of the land presently irrigated.

Operation - The trickling filters are overloaded and consequently the influent BOD of 280 mg/L is reduced to only about 100 mg/L. The holding pond is serving as an anaerobic lagoon and there is no chlorination of effluent. The spray irrigation system has priority over the 1.0 mgd of effluent, and sprinkling takes place at a rate of 2 in./day, one day per week for the 8-month growing season. The excess effluent is used by Mr. Gonzales as it flows by gravity past his property. He flood irrigates his 20 acres of alfalfa using the border strip method and irrigates 20 acres of cotton by the ridge and furrow method. The soil on both farms is a sandy loam with some alkali. The Patterson farm is so sandy that previously the land was not irrigated. The system now used is a center pivot rig, about 1,320 feet long with iron wheels. The cost in 1968 was approximately $17,000. The system operates automatically with a low pressure shutoff and seems to be a successful application. Because water is scarce the application rate is only intended to meet the needs of the crops.

Future Plans - An aerated lagoon followed by polishing ponds and sand filters for a flow of 2.0 mgd is being designed by Ralph Vail of Santa Fe. The plant will replace the existing works and provide effluent to meet the State requirement on effluent of 125 mg/L COD, 30 mg/L BOD, and 0.05 ml/L settleable solids. No standards have been set on effluent coliform levels. No changes in effluent disposal are anticipated.

San Francisco, California

The Golden Gate Park Water Reclamation plant in San Francisco produces up to 1 mgd of reclaimed water to irrigate park lawns and shrubbery. The activated sludge plant effluent is chlorinated and mixed with well water prior to application by sprinkling.

History - When the park was built in the 1870s, under the direction of Mr. McLaren, there was no adequate water supply source. He developed two well fields and diverted untreated sewage from the Lincoln Avenue sewer to a septic tank. He used the combined well water and septic tank effluent to irrigate the western half of the park.

In 1931 a suit was brought that forced the abandonment of the septic tank. A 1-mgd activated sludge plant was designed by Gilman Hyde for the McQueen Sewage Treatment Company and built near Elk Glen Lake. The effluent served as irrigation water, along with the well water, for the western part of the park until 1947. At that time a pumping plant was built at Elk Glen Lake to serve the eastern part of the park also.

Water Reclamation Plant – The water reclamation plant, put into operation in 1932, is a conventional activated sludge plant without sludge treatment. Wastewater is diverted from the Lincoln Avenue sewer, through a sand trap, a bar screen, a flash aeration basin, and into a rectangular primary sedimentation tank. Primary sludge, grit, and screenings are returned to the sewer that connects to the Richmond-Sunset plant. Primary effluent is aerated by diffused aeration in tanks that are 10 feet deep. The tanks are compartmentalized by vertical baffles into 10 bays. Because the aeration diffusers are at a depth of 3.5 feet, spiral flow throughout the depth is not accomplished. After 5 bays, the mixed liquor is transferred to the second bank of 5 bays, but the connection is near the water surface and consequently most of the solids are retained in the first 5 bays. The effluent from the No. 10 bay flows into the secondary settling tanks from which all the sludge is recirculated. The effluent is chlorinated at a dosage of 18 to 28 mg/L with a chlorine contact time of 1.5 hours.

The operation is completely manual and requires 3 men during the day and 1 man at night. Wasting of mixed liquor is from the aeration tank, and the decision to waste and the volume wasted is determined daily from experience, taking into account flow, mixed liquor suspended solids, dissolved oxygen content in the No. 10 bay, and the form of effluent nitrogen. The air supplied to the second 5 bays is half of that supplied to the first 5 bays so that there is tapered aeration.

The final effluent quality is surprisingly good with suspended solids around 10 mg/L and coliform organisms, MPN less than 2.2/100 ml. The effluent form of nitrogen is mostly ammonia although nitrification occurs periodically. In early 1972 the effluent suspended solids began to increase, and the mixed liquor suspended solids were reduced from 1,200 mg/L to 200 to 300 mg/L. The chief operator suspects that the composition of the sewage is changing because of the activity of several research hospitals in the area.

Irrigation System – About 800 acres of the park are irrigated by fixed sprinklers supplemented by hand sprinkling. Irrigation is usually required from April to October, but in some years irrigation has been required until December. The water reclamation plant generally operates from mid-February until November and produces about one-third of the water for irrigation of the 800 acres. Irrigation usually lasts for 1.5 to 3 hours with an application of about 1 inch of water. The resting period is usually 6 days. The calculated loading rate for this sandy soil is 3,750 gad or about 1 in./wk.

The groundwater does not interfere with the irrigation practice, and no test wells have been drilled. The well field in the western part of the park is declining with only 3 of the original 7 wells still producing.

Woodland, California

The municipal and industrial wastewater treatment ponds at Woodland produce up to 8.7 mgd for crop irrigation.

History – Sewage farming in Woodland began in 1889 with the irrigation of hay and pasture land east of town. In 1905 the resultant odors led to a lawsuit that forced the sewage farm to be moved. From 1905 to 1930 farming with sewage continued in a larger tract east of the original plot. The City has purchased additional land over the years so that it now owns over 1,400 acres.

In 1948 a primary sewage treatment plant was constructed on Beamer Street, and the effluent is used for irrigation. The City has built numerous ponds since that time, and now all treatment except coarse screening is accomplished in oxidation ponds.

The present municipal waste flow is 4.2 mgd, and the separate tomato canning waste averages 4.5 mgd from mid-July to October. Near the abandoned primary plant a series of ponds provides the equivalent of primary plus secondary treatment for 0.3 mgd which is then percolated into the ground. The remainder of the wastewater is treated in ponds and is made available for irrigation.

Irrigation System – The irrigation ditch runs eastward to a site near Tule Canal in the flood plain of the Yolo bypass.

The City owns 430 acres which is presently leased to Mr. C. W. Plumb. Mr. Plumb owns and irrigates 240 acres of milo north of the City's land. This year he raised safflower (a nonirrigated crop) on the City's 430 acres. He pays the City $10,000 per year for the land and has the right to the treated effluent when he needs it. On the 240 acres of milo he applied 30 inches of water per season at a rate of about 1.5 in./wk. The water is applied by flooding and the runoff is collected in a drainage ditch which discharges into Tule Canal.

The Regional Water Quality Control Board's requirements for discharge to Tule Canal are a minimum of 60 days' detention prior to discharge and a dissolved oxygen content of 5.0 mg/L in Tule Canal. When water is not needed for irrigation, the 430 acres are flooded and leased as a duck hunting area. Parts of the 320 acres of industrial waste treatment ponds are also leased for duck hunting.

Mr. Hiatt, the Public Works Director, has a good deal of experience with wastewater ponds, and the result is a well operated system. The system is flexible enough to handle breakdowns at any critical point by overflowing to another treatment pond.

Lake George, New York

The Village of Lake George disposes of trickling filter effluent by infiltration-percolation. The treatment plant is located 1 mile from the south shore of Lake George, which is 36 miles long and from 1 to 3 miles wide.

Lake George Village Sewage Treatment Plant - The Village sewage treatment plant receives wastewater from 5 pumping stations, including 2 located in the Town of Lake George. The winter flow rate is 0.3 mgd, and the summer flow rate averages 1.2 mgd. Primary treatment is provided by 2 circular Clarigesters (similar to Imhoff tanks) built in 1965 and an Imhoff tank built in 1936, all operating in parallel. During winter the Imhoff tank is taken off line. The primary effluent passes over 2 trickling filters built in 1939 and receives secondary settling. Clarified secondary effluent is piped to 21 separate percolation beds. There are no chlorination facilities. Sludge from the secondary settling tanks is returned to the Clarigesters, and digested sludge is disposed of on sand drying beds. The plant capacity is 1.75 mgd. The only problem with the operation is the peak flow delivered from the Town, which overloads the Clarigesters and results in solids carryover. An equalization basin is planned to remedy this problem.

Percolation Beds – There are 21 percolation beds, each with an area of 0.5 acre. The beds have 3- to 5-foot dikes around them, and each bed has a control valve for individual flooding. Each morning the valve is opened on a new bed, which is flooded with 8 to 10 inches of effluent over the next 9 hours. When the operators leave in the evening the next bed is put on line.

During winter the liquid loading ranges from 7 to 15 in./wk. After the 9-hour flooding the beds are rested for 5 to 10 days. When the solids on the surface are dried out, they are scraped off and the bed is ready for the next application. When ice forms on the surface, it is not removed but merely floated by the next application of effluent.

In the summer, more than 2 beds are flooded each day, but 4 to 5 days are still allowed for resting. The average loading is 15 in./wk. The material in the beds ranges from coarse to fine sand, with a few beds having some clay content. Wells have been driven down 56 feet without running into bedrock or the permanent water table. No vegetation grows in the beds because of the weekly scraping of the surface. There have been no serious problems with the operation of the percolation beds.

Environmental Effects – Mr. Harold Gordon, the Plant Superintendent, indicated that the State of New York was concerned about phosphorus buildup at the south end of Lake George due, in part, to the leaching of phosphorus through the beds and into the lake. Dr. Donald B. Aulenbach of the Environmental Engineering Division at Rensselaer Polytechnic Institute has conducted several studies in regard to environmental effects of the Lake George Village percolation beds. The results of his studies have shown a buildup of nitrates at the 10-foot depth in the beds from an initial 2 mg/L to 8 mg/L, and a phosphorus increase, in one bed, from an initial 25 to 27 mg/L. In a second, less-used bed, the phosphorus removal was 60 percent in 10 feet. Ten feet of sand were found to remove 100 percent of the organic nitrogen, 99 percent of the coliforms, and 96 percent of the BOD. Total nitrogen removal was about 40 percent.

Dr. Aulenbach also found that a mound of water was created by the percolation operation. After dosing one bed (No. 11) continuously for 2 weeks, the bed was saturated with water to a depth of 10 feet, but was no longer saturated at 15 feet. This bed was considered a "fast bed" in that the water percolated away in a day or two. Bed No. 13, which showed a 72 percent phosphorus removal in 5 feet, was only slightly used because its control valve was located in a manhole that is difficult to reach.

Dr. Aulenbach is currently planning field studies to verify the movement of effluent through the sand and ultimately into the lake. Resistivity studies have indicated a natural pathway from the beds to the lake which he plans to verify by drilling wells and sampling the groundwater. A student under Dr. Aulenbach has run effluent through sand in the laboratory, under conditions similar to those in the field, until the phsophorus uptake capacity was reached. When this occurred, he dosed the columns with distilled water, simulating rainfall, which leached the phosphorus from the sand. The results and conclusions of this study have not been published.

Phoenix, Arizona

The Flushing Meadows project near Phoenix, Arizona, is a pilot infiltration-percolation system for wastewater renovation. It is conducted under the direction of Dr. Herman Bouwer, Director of the U.S. Water Conservation Laboratory. Wastewater for the study is activated sludge effluent from the 91st Avenue plant.

History - In the Phoenix area, one-third of the agricultural water comes from groundwater. The remaining two-thirds of the irrigation water and the municipal supplies are obtained from surface reservoirs on the Salt and Verde rivers. In recent years the groundwater table in the Phoenix area has been dropping 10 ft/yr. In 1971 the water table dropped 20 feet. The depth to groundwater varies from 400 feet in the Mesa area to 50 feet near the Salt River in the Phoenix area.

Flushing Meadows Project - In 1967 the Flushing Meadows Project was begun. The objectives were to study the treatment of sewage effluent by rapid infiltration and determine infiltration rates. Specifically, the removals of BOD, suspended solids, nitrogen, fluoride, and pathogenic organisms were important. It was desired to obtain renovated water of a quality sufficiently high to permit unrestricted irrigation.

A site was located west of Phoenix within the flood plain of the Salt River. The 2-acre site was divided into 6 basins that are 20 feet wide and 700 feet long. The soil is a sandy loam made up of 2 to 3 percent clay, 50 percent silt, and 47 percent sand. Infiltration rates of 1 ft/day, or 350 ft/yr, are regularly achieved by flooding for 14 days and resting 10 to 20 days. During the 2 weeks of inundation (surcharge is about 1 foot) the infiltration rate drops from 2.5 ft/day to 1.5 ft/day, with an average of 2 ft/day. During the summer, 10 days are sufficient for drying, reaeration, and biological oxidation which restores the infiltration capacity, but winter operation requires 20 days.

Four of the beds are planted with grass. (Sudan grass, common and Giant bermuda grass, and rice have been used.) One bed is natural soil and one has been covered with 4 inches of 3/8-inch gravel overlying a 2-inch layer of coarse sand. At both ends of each bed is a critical depth flume and a liquid level recorder. The difference between the two recorders indicates the infiltration rate in the basin. At the outfall end of each basin a level control device maintains a predetermined depth of water and permits rapid drainage of the water when necessary. Numerous test wells are located within the treatment area, two are 100 feet away from the area, one is 250 feet away, and a final one is 300 feet away. Most wells are 20 feet deep, but one is 30, one is 100, and one is 250 feet deep. After 3 years of operation, treated water had not reached the well that is 300 feet away. Treated water is identified from native groundwater by its low salt content.

The permeability of the soil using well water is 4 ft/day. The groundwater table is at a depth of 10 feet. Removals were: BOD, fecal coliform, and suspended solids, essentially complete; phosphorus and fluoride, 70 percent; nitrogen, 30 percent; and boron, lead, and cadmium, essentially zero.

23rd Avenue Project – The City of Phoenix has been awarded a grant from the EPA for a project near the 23rd Avenue sewage treatment plant. This project would involve rapid infiltration of 15 mgd on 40 acres, followed by pumping of the renovated water into a nearby irrigation canal. The wastewater would have secondary treatment with activated sludge at the 23rd Avenue plant. Because the effluent suspended solids concentration is above 50 mg/L, a holding reservoir for sedimentation will be provided prior to infiltration. The existing 40-acre oxidation pond will be drained and divided into 4 parallel basins, with wells along the central median to recover the renovated water. The water table at this location is at a depth of 50 feet.

If this project proves successful, a third stage project would be built utilizing secondary effluent from the 91st Avenue wastewater treatment plant. This plant has a capacity of 60 mgd and is presently treating 72 mgd, or 80,000 acre-ft/yr. The City of Phoenix has an agreement with the

Buckeye Irrigation District that the City will allow Buckeye to use 28,000 acre-ft/yr of effluent. In exchange, Buckeye will not press claims to an equivalent volume of water it claims was lost to the District because of upstream operations by the City.

The secondary effluent flows in a channel westward past the Flushing Meadows Project (where 0.6 mgd is used as influent) and on 20 miles to the Buckeye Irrigation District. The average water use for irrigation in the area is 4.5 acre-ft/acre/yr. Because of the agreement between the City and Buckeye, the District does not publicly admit irrigating with sewage effluent, and Dr. Bouwer felt that a contact with Buckeye Irrigation District would be fruitless.

Rio Salado Project – This is another reclamation project proposed for the Mesa-Tempe area. The effluent from Mesa's 5-mgd trickling filter plant flows into the dry Salt River bed and infiltrates within a half-mile of the plant. The project would involve drilling a well to recover the water, building a flood control channel, and establishing a greenbelt area along the Salt River.

Nitrogen Studies – In addition to the field studies conducted by the Water Conservation Laboratory, laboratory studies have been conducted specifically aimed at determining nitrogen removal mechanisms. These studies have been conducted primarily by Dr. J. Clarence Lance. Dr. Lance discussed his studies and supplied copies of his publications on the subject.

It has been found that ammonia nitrogen in the sewage effluent is absorbed in the soil within the top 3 feet during inundation. During resting periods the bacteria in the soil oxidize ammonia to nitrate which frees the absorption sites. When inundation begins again, anaerobic conditions quickly prevail and some denitrification occurs; however, because of the high rate of infiltration, a slug of nitrate is flushed into the groundwater. Using the laboratory soil columns, Dr. Lance has determined that a 30 percent reduction of total nitrogen occurs. If the slug of high nitrate can be recycled, the overall nitrogen removal would be 80 percent.

After a long period of 14 days on, 10 days off, the ability of the soil to absorb ammonia decreases. At this point a change in cycle to 2 days on and 5 days off stimulates the nitrifiers and rejuvenates the ability of the soil to absorb ammonia. During this cycle denitrification essentially ceases.

Westby, Wisconsin

The system at Westby is a ridge and furrow infiltration-percolation operation. Trickling filter effluent from an 0.2-mgd plant is pumped up to the basins for disposal.

Physical System – The system consists of 8 terraced basins covering 6 acres. The basins are 70 feet wide and 460 feet long, and they have been cut into a natural hillside having a slope of about 5 percent. The furrows are approximately 16 inches wide and 9 inches deep. The ridges are 35 inches wide and planted to Reed canary grass. The grass is not cut, but is burned each spring before new growth starts.

The system was built in 1959 with an area of 3.7 acres. The silt loam soil is underlain by limestone rock at 14 to 18 feet. A comprehensive study in 1964 noted that percolation rates in the virgin soil were on the order of 10 ft/day, but that the system had lost a major part of its original infiltration capacity. The loading rate in 1964 was 11.2 in./wk, and the present loading is 8.4 in./wk. The last 2 basins were added in 1971, but the infiltration rate in them is low because of the presence of limestone and the lack of a cover crop. Since 1970 the system has been overloaded. The grass planted in the last 2 basins did not grow because the basins had to be placed into service too soon. The past 12 months (March 1972 to March 1973) have been extremely wet, and it is likely that all of the grass has been drowned out. In March 1973, all basins were standing in 1 to 3 feet of water.

Wastewater Characteristics – A two-stage trickling filter is used to treat approximately 0.2 mgd of primarily domestic wastewater. A locker plant and a small butter packing plant are in the municipal system, but the large Westby Cooperative Creamery has a separate waste disposal system. The removal efficiency of the plant in terms of BOD is 72 percent at a loading of about 4,000 lb/acre-ft/day. Although both filters are being overloaded there are no odor problems. There are summertime problems with filter flies, but use of an insecticide controls the propagation. There are no chlorination facilities. Under peak flow conditions or during times of mechanical breakdown, the wastewater can be bypassed into a dry drainage ditch. Originally (1947 to 1959), effluent was discharged to this ditch, but threatened litigation from landowners because of the odors produced ended this practice and led to the irrigation system.

Operation – The normal operation of the ridge and furrow system in the mid-1960s was to apply wastewater to 2 basins for a week and then dry for a week. During periods of high flow this drying period was reduced. In March 1973 the entire flow went to one basin per day with a resting period of 6 to 7 days. As a result of heavy rains over the past 18 months and increased wastewater flows, however, this resting period is inadequate and water stands in each basin.

In the summer months mosquitoes may propagate in standing water; however, the insecticide used to control filter flies seems to control mosquitoes in the fields also. During winter the flow continues to the basins as there is no separate storage. Observations in some winters indicate that a bridge of ice supported by the ridges would develop over the furrows and that a channel for flow of wastewater was maintained in the furrows. In more severe winters the entire mass of water will freeze causing random channeling of the applied wastewater across the basin. It should be mentioned that grading of the basins was far from perfect, resulting in imperfect distribution.

Future Plans - A new contact stabilization activated sludge plant with a capacity of 0.325 mgd has been designed for Westby by Davy Engineering Co. of La Crosse, Wisconsin. Although the City owns 40 acres of land, in addition to the 8 acres presently used for treatment and disposal, the plans call for effluent discharge to a polishing pond and thence to the drainage ditch. According to percolation tests on the 40 acres, an application rate of 10,000 gad would be excessive. Apparently the depth of soil cover over the limestone is as shallow as 2 feet in some areas.

Idaho Supreme Potato Company, Firth, Idaho

This potato processing wastewater is spray irrigated for treatment and disposal. Dr. Jay Smith, of the U.S. Department of Agriculture, is conducting a 3-year study on environmental effects. The average flow is 630,000 gpd which is applied to 80 acres by spraying at a rate of 0.29 in./day or 2 in./wk. Another 110 acres of land are available for flood irrigation. In 1971, with 50 acres of spray field, the application rate averaged 3.25 in./wk, and odor complaints were received.

The spray system, installed at a cost of $800 per acre, consists of solid set sprinklers spaced on 80-foot squares discharging at 80 to 100 psi. Nozzle sizes for the rocker jet sprinklers are 9/32 inch by 5/32 inch. All distribution piping is made of polyvinylchloride.

The soil is silty loam from the Snake River flood plain, underlain by sand and gravel. Because of the operation and nearby irrigation canals, the groundwater rises from below 20 feet to within 2 or 3 feet of the surface. In areas where this interferes with the sprinkling, the manager reduces the length of the normally 12-hour sprinkling period or skips that 5-1/2 acre plot for an irrigation cycle. The average rest period for each plot is 16 to 18 days in winter, when the sprinkling period is 24 hours, and 8 to 9 days in summer.

Two wastewater streams come from the processing plant: "silt water" from potato washing, and "white water" from potato peeling and cutting. Vacuum filters are used on silt water with the mud going to a lagoon and the filtrate to the spray field. Rotating drum screens are used on the white water with the solids reclaimed for cattle feed and the screened wastewater settled, combined with the filtrate, and pumped to the spray field.

Dr. Smith will monitor the quality changes in the soil and groundwater over the next 3 years as at Idaho Fresh Pak. Preliminary samples from a 4-foot depth collected by Jerry Hastings, Plant Manager, indicate complete removals of COD and suspended solids and 70 percent removal of total nitrogen.

The fields were planted to a mixture of Reed canary grass, meadow foxtail, and alta fescue, but the fescue has not done well. The yield of hay is 5 tons/acre. Total precipitation is 7 in./yr (rain and snow). Normal irrigation in the area is 6.5 feet in 110 days of growing season versus 8 feet in 330 days at Idaho Supreme.

Beardmore & Co., Limited, Acton, Ontario, Canada

Tannery wastewater is applied to the land by spray and ridge and furrow methods for infiltration-percolation.

History - Beardmore & Co., Limited, is old and stately. Their offices and grounds reflect a long history of profitable business, as well as a deep appreciation of quiet conservatism. With this in mind it is not surprising that their land treatment system dates back to 1951 when virtually nothing of value had been published. It is also characteristic that they would select a very capable engineer, Mr. R. R. Parker (now retired), to apply himself to the problem with only his own ingenuity to draw upon. As a result, the Beardmore system differs from other systems in a number of ways. At the outset Parker's only reference was a breezy article in Newsweek which described the "Bottomless Forest" at Seabrook Farms.

The Beardmore effluent is tannery waste which ranges in pH from 4.5 to 10.5. It is notable that the high pH is from calcium hydroxide rather than sodium, but since the hides from the abattoir are packed in salt, chlorides have now become a problem. The BOD loading, which is largely of vegetable origin, ranges between 800 and 3,000 mg/L while the water volume averages 1.25 mgd.

At the outset Mr. Parker was also confused by the then popular concept that water, instead of solids, was the problem and he set about to evaporate it by spraying. Unfortunately, there are no records, but the venture failed anyway. He next tried woods irrigation in an attempt to emulate Thornthwaite's success at Seabrook. Here he achieved a partial success but became alarmed when the trees began to die and abandoned the project. This he attributed to toxicity of the effluent, but it is more likely that the exclusion of oxygen from the aeration zone of the roots was the actual cause. He then moved his giant sprinklers (250 gpm) to a grass covered area and again had problems. Apparently the line pressure supplying the sprinklers was not consistent, and the impact upon the soil of the unbroken stream of water caused severe erosion damage.

Although Mr. Parker continued to favor the use of large nozzles for the obvious reasons of simplicity and economy, he was forced to abandon them and the eventual system began to emerge at this point. The nozzle now in use is very small--about 4.5 gpm.

For many years prior to the irrigation era, wastewater was stored in large lagoons for settling before being discharged to the receiving stream. No one knows for certain, but it is believed that this practice has been going on for 50 years or more. As a result, sediment has built up in the large lagoons to a depth of about 30 feet. Disposal of these solids was another problem which confronted Mr. Parker and more recently Mr. Greifeneder--his successor.

The Present Situation - The effluent from the Beardmore plant is now segregated into two waste streams, one with high BOD and low pH (3,000 mg/L and 4.5, respectively) and the other with low BOD (800 mg/L) and high pH. After screening, both streams are stored in winter but the second stream is aerated before storage. Both streams go directly to treatment in summer with the low concentration going to spray irrigation and the "black water" to a ridge and furrow treatment area. The low pH of the black water is caused by organic acids while the high pH of the larger stream is caused by calcium hydroxide, part of which converts to calcium carbonate. This stream also contains most of the salt.

There are roughly 200 acres in the whole operation, about half of which are in the spray field, but the company is running out of land for storage. Accordingly, there is a massive operation underway to clear the storage lagoons of accumulated sludge. The sludge has been dewatered by dehydration to the point where it will support a man's weight on the surface, but underneath it is still soft. To complicate matters further, the stumps of large trees which once grew on the bottom of the lagoons were not removed and now impede the cleaning operation.

The ridge and furrow installation is not unusual, but the flume to distribute the water is. A watertight trough about 1 square foot in cross section extends along the top of the field. The flume has gates in the bottom which can be opened to direct water into the various furrow channels. It is believed that this ridge and furrow system is a carryover from Mr. Parker's early experience when he discovered that trees were killed by the heavily loaded effluent. In any event, there is no attempt to grow vegetation on this field, and the land is disked and reshaped every year. Apparently there have been no runoff or groundwater problems which would lead to the suspicion that the material is not toxic at all.

In the spray system, surface piping is used--polyethylene, rather than aluminum. Sprinklers are spaced at 30 feet, and the field is covered in a solid set pattern. The attachment of the sprinklers is unique. Instead of a tee, a bronze tapped saddle is used to tap the lateral line. On the bottom of the saddle an 8-inch spike has been brazed to the clamp, and the threaded outlet faces upward. Thus, when the spike is pushed into the ground, the sprinkler is automatically vertical. The sprinklers are screwed into the saddle without a riser.

During the first few years of operation there were odor complaints when the water in the lagoon went septic following the spring turnover. At first, masking agents were used, but later the stored water was sprayed first and in high volume, at a rate of 2 in./day and 360 lb BOD/acre/day. Spraying is begun as soon as the grass begins to green and continues nonstop until all of the stored water is distributed. Later the application is reduced to 0.46 in./day and 83 lb BOD/acre/day. During some of his early experience Mr. Parker applied up to 600 lb BOD/day for 30 days continuously without adverse effect.

Grass management by Beardmore is unique and effective. The company learned early that legumes--clover and alfalfa--could not survive and, with the advice of the Canadian Department of Agriculture, they worked out a mixture of hydrophytic species. These survived for a few years but were gradually replaced by Twitch Grass--normally considered a weed. Although the fields produced hay of good quality, the cost of harvest and disposal did not justify the return. After many false starts, a hammer mill type mower was selected, and weekly mowing now keeps the grass to a height of 2 to 5 inches. The cuttings are not collected, and there has been no detrimental effect, except that each field is out of service for about 30 days per year. With so much reserve capacity, however, this is not a problem. The Beardmore installation is the only known system to maintain such close control of grass.

The cost of the Beardmore system is high, and the operating cost is even higher. Mr. Parker reported a capital cost of $2,000 per acre--about the same as a solid set buried system with automatic controls. The operating cost is more than double that of Seabrook Farms, which handles ten times the gallonage. It should be pointed out that such figures are seldom reliable since no two companies use the same cost accounting system. For example, Beardmore may be redistributing executive management cost to all operations while Seabrook does not.

The experience of Beardmore with winter operation parallels that of many other companies and contradicts as many more. They believe that whenever the temperature drops to 20 deg F for several days, the spraying season is over. They avoid the buildup of ice on the soil in the belief that vegetation is injured, and storage for 5 months in lagoons is provided. By contrast, at Seabrook, ice mounds are created deliberately during freezing weather in order to store water. There has never been damage to the vegetation. Throughout northern United States, managers of spray systems argue this point endlessly with neither side giving ground.

Another unique experience at Beardmore is noteworthy. As mentioned above, the installation relies upon infiltration and percolation, and will handle a very respectable 2 in./day. However, the exaggerated claims for Seabrook in the Newsweek article made it appear that 2 inches was not sufficient. In order to improve the percolation rate, underdrains were installed in a 1/2-acre plot at a depth of 6 feet. The discharge from these pipes was erratic in quality, ranging from 10 to 300 mg/L BOD. Quite obviously there was a short-circuit somewhere, but they were never able to find it and the project was abandoned.

Recently the company has encountered stiff opposition from the pollution control authorities who object to the chloride discharge. As mentioned previously, the hides have been salted at the abattoir when received, and this salt is removed during tanning. At times the salt content of the water reaches 3,300 mg/L--500 mg/L is usually accepted as the threshold of taste. There was considerable concern originally that the high SAR--30--would cause "puddling" of the soil (i.e., dispersion of the crumb structure as sodium replaced calcium on the soil micelles). However, these reactions are always on a mass balance basis, and when a sufficient number of calcium ions are present the exchange does not take place. In this case about 1 ton of calcium carbonate per acre per year is normally contained in the wastewater, and this is sufficient to keep the sodium moving along as sodium chloride.

While this leaching process is great for the spray fields it is not so good for the groundwater, and there has been much pother because of increased chlorides in water wells. Chlorides are always a problem for industries which use salt in their process because there is no easy way to remove them from wastewater. For a small company like Beardmore the only practical solution for handling chlorides is by dilution, and this they have done by locating the spray field far away from dwellings and water wells. Recently, however, a developer constructed homes close to the Beardmore property, and the residents complained about the chloride content of the drinking water. To put this into perspective one must be aware that the U.S. Public Health limitation for drinking water is 250 mg/L, while the water from the wells in question was only 120 mg/L. Nevertheless, Beardmore was forced to give up 30 acres that were formerly used and to construct a 2-mile pipeline to supply the residents with city water.

This problem appears to have no end, and the existence of the company is threatened. Within the regulatory group are a number of young idealists who have allegedly produced medical evidence that chlorides produce heart disease. The residents involved are led to believe that if they drink the water they will die. There appears to be no way to stop this scare-mongering and to put the problem in proper perspective. However, a practical limit to future restrictions may be established by the fact that the city sewerage system discharges 100 mg/L of chlorides, a major portion of which is present in the fresh water supply. The city, incidentally, is a bedroom community with no large industry except Beardmore.

Table 30. Detailed Data on Land Application Sites Visited for This Study

Facility name	Type of wastewater	Pretreatment	Average flow, mgd	Year started
Abilene, Texas	Municipal	Activated sludge, effluent chlorination	4.5	1920
Moulton-Niguel WD, California	Municipal	Activated sludge, tertiary filtration, effluent chlorination	0.5	1966
Portales, New Mexico	Municipal	Trickling filters	1.0	1935
San Francisco, California	Municipal	Activated sludge, effluent chlorination	1.0	1932
Woodland, California	50% municipal 50% canning	Oxidation ponds	8.7	1889
Lake George, New York	Municipal	Trickling filters	1.2[a] 0.3[b]	1936
Phoenix, Arizona	Municipal	Activated sludge	0.67	1967
Westby, Wisconsin	Municipal	Trickling filters	0.2	1959
Idaho Supreme Potato Co., Firth, Idaho	Potato processing	Screens	0.63	1969
Beardmore & Co. Ltd., Acton, Ontario, Canada	Tannery	Screens, aeration	1.25	1951

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a. Summer.

b. Winter

Table 30 (Continued)

	Area, acres				
Facility name	Used	Irrigation	Buffer	Unused	Storage
Abilene, Texas	2,019	1,550	--	--	400
Moulton-Niguel WD, California	163	160	50 ft	14	3
Portales, New Mexico	160	160	--	--	3
San Francisco, California	1,000	800	--	200	1.2
Woodland, California	1,400	240	--	--	120
Lake George, New York	10.5	--	--	--	--
Phoenix, Arizona	2	--	--	--	--
Westby, Wisconsin	6	6	--	--	--
Idaho Supreme Potato Co., Firth, Idaho	80	80	--	110	--
Beardmore & Co. Ltd., Acton Ontario, Canada	400	100	35	200	25

Table 30 (Continued)

Facility name	Months used	Volume of storage, acre-ft	Method of application	Application rate, in./day
Abilene, Texas	5	1,850	Border strip	6
Moulton-Niguel WD, California	7	25	Spray	1
Portales, New Mexico	8	35	Spray, ridge and furrow, flooding	2
San Francisco, California	7	6	Spray	1
Woodland, California	6	1,660	Flooding, ridge and furrow	3
Lake George, New York	12	--	Spreading	8-10[a] 8[b]
Phoenix, Arizona	12	--	Spreading	24
Westby, Wisconsin	12	--	Ridge and furrow	1.2
Idaho Supreme Potato Co., Firth, Idaho	12	--	Spray	5
Beardmore & Co. Ltd., Acton, Ontario, Canada	9	300	Spray, ridge and furrow	0.5

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a. Summer.

b. Winter.

Table 30 (Continued)

Facility name	Drying period, days	Liquid loading rate, in./wk	Annual liquid load, ft/yr	Organic loading rate, lb BOD/ acre/yr	Nitrogen loading rate, lb N/ acre/yr
Abilene, Texas	10-14	3	2.0	92	65
Moulton-Niguel WD, California	1-2	2	5.0	405	108
Portales, New Mexico	6	2	5.8	1,565	--
San Francisco, California	6	1	2.5	51	337
Woodland, California	12	1.5	2.5	284	72
Lake George, New York	4-5[a] 5-10[b]	30[a] 7[b]	65	6,800	2,950
Phoenix, Arizona	10-20	84	400	10,800	23,800
Westby, Wisconsin	14 of 28	8.3	36	3,200	3,080
Idaho Supreme Potato Co., Firth, Idaho	16-18	2	8.7	--	2,900
Beardmore & Co. Ltd., Acton, Ontario, Canada	1	3.5	11.4	25,000	--

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a. Summer.

b. Winter.

Table 30 (Continued)

			Geology		
Facility name	Soil type	Crop	Depth to impervious layer, ft	Depth to ground-water, ft	Slope %
Abilene, Texas	Clay loam	Cotton, maize, coastal bermuda grass	<100	14-16	< 2
Moulton-Niguel WD, California	Clay	Bermuda grass	--	--	> 2 < 6
Portales, New Mexico	Sandy loam	Alfalfa, cotton, wheat	--	--	< 2
San Francisco, California	Sand	Grass	Variable	Variable	< 2
Woodland, California	Clay loam	Milo	--	80	< 2
Lake George, New York	Sand	--	50	40	< 2
Phoenix, Arizona	Sandy loam	--	250	10	< 2
Westby, Wisconsin	Silt loam	Reed canary grass	14-18	> 200	> 2 < 6
Idaho Supreme Potato Co., Firth, Idaho	Silt loam	Grass	4	3-10	< 2
Beardmore & Co. Ltd., Acton, Ontario, Canada	Clay loam	Grass	--	Variable	> 2 < 6

Table 30 (Continued)

	Costs				
Facility name	Land, $/acre	Annual operations budget, $	System cost, $	Year for capital costs	Annual return, $
Abilene, Texas	300	221,000	--	--	17,000
Moulton-Niguel WD, California	--	--	240,000	1966	350
Portales, New Mexico	--	--	17,000	1968	675
San Francisco, California	--	<95,000	52,875	1932	--
Woodland, California	100-500	50,000	--	--	10,000
Lake George, New York	--	--	--	--	--
Phoenix, Arizona	--	--	--	--	--
Westby, Wisconsin	750	--	10,000	1959	--
Idaho Supreme Potato Co., Firth, Idaho	600-800	--	64,000	1969	--
Beardmore & Co. Ltd., Acton, Ontario, Canada	--	34,000	--	--	--

Table 30 (Continued)

Facility name	Climate Zone[c]	BOD, mg/L To land	BOD, mg/L To ground water	COD, mg/L To land	COD, mg/L To ground water
Abilene, Texas	B	17	--	84	--
Moulton-Niguel WD, California	A	30	--	79	--
Portales, New Mexico	B	100	--	--	--
San Francisco, California	A	5-10	--	--	--
Woodland, California	A	42	--	--	--
Lake George, New York	E	30-46	1.5	--	--
Phoenix, Arizona	B	10-20	0-1	30-60	10-20
Westby, Wisconsin	E	33	4	118	42
Idaho Supreme Potato Co., Firth, Idaho	E	--	--	1,300-2,800	0
Beardmore & Co. Ltd., Acton, Ontario, Canada	E	800-3,000	--	--	--

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c. As defined in Figure 10.

Table 30 (Continued)

Facility name	SS, mg/L		pH	
	To land	To ground water	To land	To ground water
Abilene, Texas	12	--	7.1	--
Moulton-Niguel WD, California	19	--	7.7	--
Portales, New Mexico	--	--	--	--
San Francisco, California	5-15	--	--	--
Woodland, California	88	--	9.8	--
Lake George, New York	--	--	--	--
Phoenix, Arizona	50-100	0	7.7-8.1	6.9-7.2
Westby, Wisconsin	85	--	7.2	--
Idaho Supreme Potato Co., Firth, Idaho	500	0	6.8	--
Beardmore & Co. Ltd., Acton Ontario, Canada	--	--	4.5-10.5	--

Table 30 (Continued)

	E.Coli		Total P, mg/L	
Facility name	To land	To ground water	To land	To ground water
Abilene, Texas	--	--	29	--
Moulton-Niguel WD, California	2.2 MPN	--	--	--
Portales, New Mexico	--	--	--	--
San Francisco, California	<2.2 MPN	--	1-10	--
Woodland, California	1.3×10^5	--	7.9	--
Lake George, New York	970	8	25.4	27.5
Phoenix, Arizona	10^5-10^6	0-100	7-12	4-8
Westby, Wisconsin	--	--	29.5	2
Idaho Supreme Potato Co., Firth, Idaho	--	--	--	--
Beardmore & Co. Ltd., Acton, Ontario, Canada	--	--	--	--

Table 30 (Continued)

	Total N, mg/L		TDS, mg/L	
Facility name	To land	To ground water	To land	To ground water
Abilene, Texas	12	--	750	--
Moulton-Niguel WD, California	8	--	1,046	--
Portales, New Mexico	--	--	--	--
San Francisco, California	40-60	--	--	--
Woodland, California	10.6	--	--	--
Lake George, New York	16.7	10.5	--	--
Phoenix, Arizona	22-47	5.8-70.7	1,000-1,200	1,000-1,200
Westby, Wisconsin	31.6	9.4	480	--
Idaho Supreme Potato Co., Firth, Idaho	123	38	--	--
Beardmore & Co. Ltd., Acton, Ontario, Canada	--	--	3,500-6,000	--

Table 30 (Continued)

Facility name	Alkalinity, mg/L		Sodium, mg/L	
	To land	To ground water	To land	To ground water
Abilene, Texas	196	--	192	--
Moulton-Niguel WD, California	209	--	192	--
Portales, New Mexico	--	--	--	--
San Francisco, California	--	--	--	--
Woodland, California	695	--	--	--
Lake George, New York	--	--	--	--
Phoenix, Arizona	--	--	200	--
Westby, Wisconsin	--	--	74	--
Idaho Supreme Potato Co., Firth, Idaho	--	--	--	--
Beardmore & Co. Ltd., Acton, Ontario, Canada	--	--	--	--

Table 30. (Concluded)

Facility name	Calcium, mg/L To land	Calcium, mg/L To ground water	Magnesium, mg/L To land	Magnesium, mg/L To ground water	Potassium, mg/L To land	Potassium, mg/L To ground water
Abilene, Texas	17	--	44	--	36	--
Moulton-Niguel WD, California	99	--	22	--	15	--
Portales, New Mexico	--	--	--	--	--	--
San Francisco, California	--	--	--	--	--	--
Woodland, California	--	--	--	--	--	--
Lake George, New York	--	--	--	--	--	--
Phoenix, Arizona	82	--	36	--	8	--
Westby, Wisconsin	36	--	26	--	--	--
Idaho Supreme Potato Co., Firth, Idaho	--	--	--	--	--	--
Beardmore & Co. Ltd., Acton, Ontario, Canada	--	--	--	--	--	--

SITES VISITED PRIOR TO STUDY

In addition to the nine sites in the United States and the one in Canada visited as a key part of the data collection activity, 11 sites were visited prior to and apart from the study. Information on these sites, two of which are municipal and nine of which are industrial, is included here. The municipal sites, which use irrigation, are Bakersfield, California, and Mount Vernon Sanitary District, California. The industrial sites include four overland flow systems and five spray irrigation systems. The overland flow sites include three installations for the Campbell Soup Company at Chestertown, Maryland, Napoleon, Ohio, and Paris, Texas; and one installation for Hunt-Wesson Foods, Inc., at Davis, California. The five spray irrigation systems are for California Canners & Growers, Thornton, California; Campbell Soup Company, Sumter, South Carolina; Seabrook Farms Company, Seabrook, New Jersey; Sebastopol, California; and Tri/Valley Growers, Stockton, California.

Bakersfield, California

Municipal wastewater has been used to irrigate cropland at Bakersfield since 1912. The City has two primary treatment plants. Plant No. 1 was built in 1939 and has a capacity of 5.5 mgd, while Plant No. 2, built in 1952, has a capacity of 16.0 mgd. The effluent from the plants is blended and is not disinfected.

The effluent is transmitted to the irrigation site by gravity, and irrigation is primarily by the ridge and furrow method with some flood irrigation. The present flow of 11.3 mgd is used to irrigate approximately 2,400 acres of crops, including cotton, corn, barley, alfalfa, and pasture. The land is leased to a local farmer who controls the planting and irrigation scheduling. Soil types vary but the primary type is clay loam. Liquid loading rates average 1.2 in./wk.

There are no provisions for storage of excess effluent. Consequently, a significant amount of water in excess of irrigation requirements must be applied to the land during the winter months. This excess is normally applied to pasture land which is least affected by excessive irrigation. Water not consumed by the crop is lost to deep seepage and runoff to low-lying areas south of the site. The water lost to runoff floods these low lands and stands until it is ultimately lost to deep seepage and evaporation. Conversely, the summer irrigation requirements are in excess of the sewage flow, and groundwater must be pumped to make up the difference.

Mount Vernon Sanitary District, California

Effluent from the Mount Vernon trickling filter plant (3.6 mgd) is discharged onto approximately 1,000 acres of irrigated land adjacent to the City of Bakersfield irrigation site. During fiscal year 1970-1971, however, only 650 acres were cultivated. The crops grown on the Mount Vernon farm during 1970-1971 include alfalfa, pasture, and barley. These crops are flood irrigated at a loading of 1.4 in./wk. The clay loam soil, when irrigation began in 1948, was alkaline in nature. The alkaline condition has been amended by leaching with excess irrigation water and the addition of gypsum. Originally, the land cost $65 per acre and its present value is about $1,000 per acre. As at the Bakersfield farm, excess effluent is applied to pasture land during winter months with runoff collecting on low-lying areas to the south. This imbalance is magnified at times because the Mount Vernon plant does not have sufficient equalizing reservoir capacity that would allow constant application rates of irrigation water.

Campbell Soup Company, Chestertown, Maryland

The Chestertown plant is also a poultry processing operation that does not include killing and eviscerating. Production began early in 1960. A new concept of wastewater irrigation, one known as the "bubbling orifice" principle, was attempted. In this concept, the raw wastewater, after screening, is distributed to the irrigation fields by a network of underground gravity-flow pipes. At regularly spaced intervals, 1-inch riser pipes extend up from the distribution pipe to just above the ground surface. Little or no attempt was made to change the contour of the existing land. As the wastewater "bubbled" out onto the ground, it followed the normal contours of the land, and eventually the major volume of water percolated into the soil.

The bubbling orifice system was found to have several serious shortcomings. Since all of the flow was by gravity, the distribution of wastewater onto the land was poor. Also, because of gravity flow, solids and grease had a tendency to settle out and coat the piping distribution system, sometimes to the point where lines would become entirely blocked. Finally, poor land utilization resulted in severe limitations to the treatment capacity. Because of the poor efficiency of the bubbling orifice system, the plant embarked on a program of replacing the bubbler system with a high pressure spray irrigation system.

The soils at Chestertown are unique in that some are sandy while others contain a high percentage of clay. Therefore, a combination of both infiltration-percolation and overland flow systems was created. Roughly 80 acres of clay soil were graded and reshaped to form a series of slopes and runoff terraces, discharging into a receiving stream. An additional 20 acres of sandy soil was utilized for infiltration-percolation. To improve the infiltration capacity of these sandy soils, perforated drainage pipe was installed at a 5-foot depth with its discharge routed to the receiving stream.

The wastewater pretreatment operation consists of screening and gravity grease removal. Sanitary sewage is treated separately. The high pressure pumps transfer the wastewater to the spray fields via an asbestos-cement force main. In the overland flow portion of the fields, the water is distributed onto the slopes through surface aluminum pipe and sprinklers. The slopes range from 175 to 250 feet in width, with sprinklers spaced 80 feet apart along each line. In the infiltration section of the system, the lateral piping is underground polyvinylchloride pipe, with sprinklers spaced on a 100- by 80-foot grid. All of the treated effluent from both parts of the system, with the exception of that which escapes into the groundwater, is collected and chlorinated before being discharged to the stream.

The control system at Chestertown is identical to those at the other Campbell operations in Paris, Sumter, and Napoleon. Reed canary grass is also utilized, and the same microbiological activity exists throughout the system.

The quantity of wastewater discharged to the treatment system is approximately 700,000 gpd. Although the total area involved is approximately 100 acres, only about 70 of these can be considered wetted acres. This results in an average rate of about 0.4 in./day.

The treatment efficiency of the Chestertown system averages more than 99 percent BOD removal. The BOD of the raw and treated wastewater average 800 mg/L and 5 mg/L, respectively, while the suspended solids average 348 mg/L and 28 mg/L.

Campbell Soup Company, Napoleon, Ohio

The overland flow technique was pioneered at this soup production plant in 1954. A 300-acre site adjacent to the plant was selected to provide treatment for peak wastewater loads generated by increased processing activity during tomato season, when the daily average wastewater volume is nearly doubled and too great in quantity for the conventional trickling filter system, which normally accommodates processing water for 10 months a year. Therefore, all flows above the design capacity of the conventional system are routed to the overland flow system.

The soils of Napoleon are silt and clay and were originally deposited during the ablation period of the Wisconsin glacier when Lake Maumee covered a vast area in northwestern Ohio. Therefore, with the exception of a sandy ridge across the property (which was formerly a beach), the soils are characterized by low infiltration and low permeability. This established a severe limitation on the quantity of water that would infiltrate into the soil as normally occurs in conventional spray irrigation systems. In an effort to overcome this, the natural terrain of the land was utilized, and irrigation pipe was located near the top of individual slopes. This pipe distributed the water along the crest of the slopes from whence it flowed downhill slowly over the soil surface and became purified enroute. Little emphasis was placed on the quantity of water that actually infiltrated into the soil mantle.

It was found that, if operated correctly, this system of "overland flow" achieved excellent wastewater treatment efficiency. Although the original installation was successful, it was soon evident that better land use efficiency would have greatly reduced the installation cost. Nevertheless, it provided an excellent background for the establishment of other systems, particularly those in Paris, Texas, and Chestertown, Maryland. Experience with these systems led to even further design refinements, and the Napoleon installation is presently undergoing a program of redevelopment. Utilizing the information gained from operations in Paris, the original slopes are being regraded for better land utilization and greater treatment capacity.

The Napoleon plant processes canned food consisting chiefly of vegetables. The pretreatment facilities consist of screening and gravity grease separation. The high pressure pumping system discharges into an underground force main which delivers the wastewater to the spray fields. The newly developed slopes range in width from 175 to 200 feet, with polyvinylchloride pipe buried along the top of each. Sprinklers are spaced at 80-foot intervals along each lateral pipeline. In the older areas where the land has not been regraded, the slope lengths vary widely, and portable aluminum pipe is connected to the force main system and laid along the surface of the ground. There are close to 700 sprinklers in the total system. The automatic control system is similar to that of the other company systems and will be described in the Paris, Texas, section.

As mentioned previously, the main purpose of the Napoleon spray irrigation system is to protect its conventional wastewater treatment system from overloads, particularly during tomato season. Therefore, the spray system receives its heaviest use during the late summer months. It is also used to a limited extent in the spring and early summer, but not during the winter months, although it could be used in winter if that became necessary.

The grass on the fields is primarily Reed canary and Alta fescue. It is harvested at least once a year and utilized in the growing of mushrooms.

During the late summer months, approximately 4 mgd of wastewater flows to the spray irrigation system. About 250 wetted acres are presently being used, resulting in an application rate of 0.6 in./day. The land use efficiency is about 75 percent, i.e., 335 field acres. The average BOD and suspended solids of the applied wastewater are 400 mg/L and 358 mg/L, respectively. The BOD of the treated effluent averages 19 mg/L, while the suspended solids average 28 mg/L.

Campbell Soup Company, Paris, Texas

The wastewater treatment system at Campbell's plant in Paris, Texas, was designed to treat all of the wastewater generated by the food processing operation. The Paris facility is also a soup plant. The only wastewater not treated by the company's spray irrigation system is the sanitary sewage. This rather small portion of the total water usage is directed to a municipal wastewater treatment system operated by the City of Paris.

The development of the Paris plant overland flow system was complicated by several factors. The land available for spray irrigation had been a victim of extremely poor farming and soil conservation practices during the cotton boom of the early 1900s, which resulted in severe soil erosion over most of the acreage. Around 1940 the land was abandoned until purchased by the company in 1960. By this time, most of the topsoil had disappeared and deep erosion gullies scarred the land.

The local soils are red clay overlaid by a gray clay loam. The infiltration capacity is very low--about 0.10 in./day--which precludes the use of the standard infiltration-type of spray application. Based on the early experience gained at Napoleon, Ohio, a plan was advanced for the development of an overland flow spray system. Unlike the Napoleon system, where gently rolling topography made it relatively easy to construct an overland flow system, the devastated land at Paris necessitated a complete overhaul. Using heavy earthmoving equipment, approximately 500 acres of land were transformed into a network of slopes and terraces. The entire area was seeded, fertilized, and irrigated with fresh water, to establish a good growth of sod prior to the application of wastewater.

Before being discharged into the spray irrigation system, the food processing wastewater is routed through a gravity grease separator complete with mechanical grease skimming and bottom sludge removal, and then through a series of rotary drum screens. The screened water is then pumped into the spray system by high pressure pumps. An asbestos cement force main system distributes the wastewater to 123 automatic valves located on each of the individual slopes, from whence it is applied to land via aluminum surface piping and sprinklers. After 10 years of experience the worn aluminum piping is being slowly replaced by buried polyvinylchloride piping. There are more than 700 sprinklers in the system with discharge varying between 14 and 30 gpm. Most of the sprinklers are spaced 80 feet apart on each line, while the individual slopes are all somewhere between 200 and 300 feet wide. The pitch of the slopes varies between 1 and 12 percent, and this was more or less dictated by the existing topography and the balance of cuts and fills in the earthmoving operation. The slopes vary in length from 350 to 1,300 feet.

The entire system is automatically controlled, utilizing pneumatic valves in the field. The pumping system is controlled by a standard liquid level control system located in the pump reservoir. These controls are electrically connected to four modified golf course type clock timers. When the level control system activates an individual pump, the pump starting circuit energizes a clock timer. The timer is connected to the individual field valves by a network of underground polyethylene tubing which supplies compressed air to close the valves. A plug board used for grouping and regrouping the various sprinkler lines is integrated with the clock timers. Activation of the clock timers by the pumping system results in the opening of a set of valves which had been prescheduled by the plug board arrangement. The timer keeps that particular set of valves open for a predetermined period of time and then automatically closes that set and opens another, and so on.

After the wastewater is distributed along the top of the slope, it trickles downward across each slope to the terraces at the bottom. These terraces run together to form larger waterways, and eventually all the waterways flow into a small stream which runs through and away from the plant property. The wastewater is purified in this process by several means. The major treatment mechanism is the biological activity of the microorganisms present on the soil and in the vegetative growth. These organisms convert the organic compounds contained in the waste back into the harmless basic elements. The grass also captures the nutrients contained in the water and utilizes them for growth.

Once a set of sprinkler lines is activated, it is programmed to run for 6 to 8 hours continuously. A rest period of at least twice the length of the operating cycle is also programmed into the controller. Grass cutting and harvesting cause alterations to this schedule, but only about twice a year.

Since the Paris system is built on clay soil, little infiltration occurs. In fact, only about 20 percent of the applied volume of wastewater finds its way into the soil, while an additional 20 percent is lost through evapotranspiration, and the remaining 60 percent flows into the waterways and away from the property.

The treatment facility was originally expected to be capable of treating approximately 3.5 mgd. Although the 500 acres of irrigation land were reshaped specifically for treatment purposes, experience has shown that land utilization at Paris is only fair. For example, effective treatment can be achieved with slopes of only 175 feet in width rather than the 200- to 300-foot slopes. Also, the optimum pitch of the individual slopes has been found to be 2 and 6 percent. The original design of the spray system assumed application rates of 0.25 in./day and 0.50 in./day in winter and summer, respectively. This was based on an estimated wetted area coverage of about 75 percent. The actual application, however, resulted in a wetted area coverage of less than anticipated and, therefore, an application rate averaging approximately 0.60 in./day.

The treatment efficiency of the system has continuously been extremely high, as witnessed by the data in Table 31. For example, the BOD removal averages greater than 98 percent. One other aspect of the system that merits comment, and that can also be seen in the same table, is the tremendous buffering capacity of the system. Although the quality of the applied wastewater varies quite widely (notice the range of pH and conductivity) during a typical 24-hour period, the quality of treated effluent remains quite constant.

Table 31. Wastewater Characteristics of Plant at Paris, Texas

Characteristic	Raw wastewater	Treated effluent
BOD, mg/L	490	8
Suspended solids, mg/L	245	24
Total solids, mg/L	500	262
COD, mg/L	740	33
pH, range	5.1-9.3	6.2-8.0
Conductivity, micromhos, range	330-800	400-530

A byproduct of the system is the grass which is grown on the fields. Reed canary grass has been found to be especially well suited to the spray application, and has yielded large quantities of high quality hay. Based on actual nutritional analyses, this hay is equal to most high quality alfalfa, and when sold as a cash crop, returns at least 5 percent of the operating cost of the system.

Production increases during the past few years have generated larger quantities of wastewater to be treated. Present volumes exceed 4 mgd at times. Therefore, an additional 140 acres of land were added to the original system and were put into use during January 1973.

Hunt-Wesson Foods, Inc., Davis, California

This tomato canning plant produces up to 4 mgd of wastewater which is treated by overland flow. Screened wastewater is pumped to the field and sprayed onto 2.5 percent slopes. Total site area is 320 acres although approximately 250 are field acres. The system was put into operation in 1971.

A series of 28 benches were built in a sawtooth manner. Each bench is 175 feet wide and 2,400 feet long. In addition to commercial fertilizer, gypsum was added to the clay soil at 12 tons/acre to promote grass growth. The field was planted to a mixture of Reed canary, fescue, trefoil, and Italian rye grasses. Reed canary grass has emerged but has not become the dominant species after 2 years of operation.

The sprinkler system has buried laterals. Sprinklers are spaced every 100 feet along the 2,400-foot bench, and they are 65 feet from the top of the 175-foot slope. Individual sprinklers discharge 25 gpm at 60 psi for an effective diameter of 130 feet.

Capital costs in 1970-1971 were about $1 million, and operating costs range from $20,000 to $40,000 depending on the hay crop. The first cutting in 1971 yielded 1 ton/acre, while the cutting in 1972 yielded 1.5 ton/acre.

Runoff water is collected in a concrete pond for monitoring prior to discharge to the adjacent drainage channel. Monitoring is for pH in the wastewater and dissolved oxygen in the channel.

California Canners & Growers, Thornton, California

This cannery in northern San Joaquin County processes tomatoes and produces 2.5 to 3.0 mgd of wastewater. Operation generally runs from mid-July to October. Wastewater is applied to the land by spraying on about 60 acres and by flooding on about 65 acres.

The average loading rate is 0.7 in./day on a very fine sandy loam soil. This rate is excessive, and by late September approximately 40 percent of the applied water appears as runoff. This water is collected in a common sump and discharged to the Mokelumne River.

Approximately 20 acres of ponds are available for pretreatment; however, only one pond was used in 1972 as a settling basin prior to the wastewater pumping station. The wastewater is pumped to the spray field for 30 minutes on each of 8 sprinkler settings. The wastewater then goes to the flood field for 4 hours, where it is distributed by gated pipe.

As a consequence of the heavy liquid loading, mosquito and psychodid propagation has occurred. The frequent applications maintain an excellent habitat for these insects in the nut grass. In response to these problems and some odor complaints, the company is purchasing additional land for flood irrigation.

Campbell Soup Company, Sumter, South Carolina

Campbell's plant at Sumter, South Carolina, is a large poultry processing facility which went into operation during 1965. A spray irrigation system was designed to treat the entire plant wastewater on a year-round basis. Sanitary sewage is treated separately.

The land available was nearly flat, and the soils contained a high percentage of medium sand with extremely high infiltration capacity--on the order of 10 in./hr surface infiltration. Although this situation seemed to lend itself perfectly to the conventional infiltration type of spray irrigation, the sandy clay understructure seriously limited the downward percolation of water.

To overcome this barrier, which was located about 6 feet below the surface, perforated drainage pipe was installed in a network which covered approximately 150 acres of land at a depth of 5 feet. This allowed full use of the high infiltration sand layer above the drainage pipes and provided a route of escape for the purified water that could not penetrate the sandy clay subsoil.

Scattered throughout the Sumter region are shallow depressions in the soil which are believed to have been caused by a meteor shower. These depressions, which are known as "Carolina Bays," are usually 6 to 8 feet deep and range in size from 1 to 100 acres. A 57-acre "bay," which had been artificially drained, lay in the path of the natural drainage from the treatment area, and since there was no way to avoid it, the company decided to dam the outlet and convert the bay into a lake. After a couple years of ecological adjustment, the lake has now become a beautiful wildlife preserve, which is literally teeming with fish, reptiles, and water fowl in perfect ecological balance.

Because of the nature of the processing operation, a large amount of solids and grease are generated. Feathers and offal are collected in separate screening systems, each consisting of rotary drum screens. Grease is separated from the wastewater in a vacuum flotation system. All solids collected in the pretreatment system are sold to a rendering operation.

The wastewater is distributed to the spray irrigation system by high pressure pumps and a control system with clock timers and pneumatic valves similar to the arrangement at Paris, Texas. All of the pipe in the Sumter system is buried. The force main from the pumps to the individual valves is asbestos-cement pipe, while the smaller lateral lines are polyvinylchloride. There are over 600 sprinklers in the system which discharge between 20 and 30 gpm each.

The field system consists of two separate areas. The older original network is approximately 100 acres, while the newer section is roughly 50 acres. The piping layout in the first section is such that the sprinklers are located on a 120-foot triangular spacing pattern. Experience has shown that better land utilization could have been achieved with no lessening of treatment efficiency by reducing this spacing. Therefore, the newer 50-acre portion of the field, which went into full-scale operation in 1971, utilizes a grid pattern of 80 by 100 feet for sprinkler spacing.

Since the spray irrigation principle at Sumter is infiltration, only minor changes to the existing topography were needed. As the wastewater is applied to the land it soaks directly into the soil. Part of the water percolates through the sand-clay strata and into the groundwater reserve; the remainder is picked up by the perforated drainage pipe. Reed canary grass is the dominant species in the Sumter system. The operational schedule consists of 6 hours of continuous spraying on any particular cycle and 12 or more hours of rest.

The Sumter system treats an average of 3.5 to 4.0 mgd of wastewater. Spread over 150 acres, this amounts to an application rate of approximately 0.9 in./day. Treatment efficiency is excellent, with BOD reduction averaging above 99 percent. The raw and treated wastewater characteristics were given in Table 23 in Section VI.

Seabrook Farms Company, Seabrook, New Jersey

The spray irrigation system of Seabrook Farms Company has been in continuous operation since June 1950, receiving an annual application of 1.25 billion gallons of wastewater distributed over an area of 310 gross acres. The wastewater, which originates from processing of vegetables, ranges in BOD from about 200 mg/L to around 2,000 mg/L depending upon the product being processed. (All sanitary waste is treated separately, and the treated water is not mixed with industrial waste stream.) The quantity of water is also highly variable, ranging from a few hundred thousand gallons per day in winter to 16.0 mgd at the height of the packing season.

The problem of stream pollution was recognized during the late 1930s, but because of the wartime shortage of construction materials, little pollution control was attempted--save the construction of some lagoons which by 1946 were totally inadequate. During the next 2 years engineering studies led to no feasible means of pollution control that was within the company's financial capability. Finally, the company asked Dr. C. Warren Thornthwaite to investigate the possibility of disposal by irrigation.

Effluent of the quality produced by Seabrook Farms is entirely suitable for crop irrigation and indeed had been used for this purpose for many years. However, crop demands for water do not coincide seasonally with the harvest schedule. In fact, during the asparagus season in spring and again during spinach harvest in the fall, excess moisture from rainfall is always a threat and often a problem. Therefore, Thornthwaite's first task was to locate fields within piping distance of the factory which would be in cover crop during high rainfall periods and to discover by trial just how much water these fields could be expected to absorb. It is, perhaps, fortunate that the irrigation experiments at Pennsylvania State University were to come 15 years later. That is, if Thornthwaite had been constrained by the concept of 2 in./wk, he would have abandoned the project before it got started, since the 1,800 acres needed to handle 14.0 mgd were simply unavailable.

During periods of drought in the humid East, farmers normally apply 1 inch of irrigation water about once a week. Therefore, it was necessary to learn how much more water the land would accept. To achieve this, Thornthwaite set up a single giant sprinkler in a sandy field with a vigorously growing cover crop of crimson clover. The results were disappointing. After the application of 2 inches, the soil was waterlogged and became waterlogged again with the application of only a fraction of an inch on successive days. Clearly, something was impeding the movement of water through the soil--probably plow sole which had been formed during 100 years of tillage.

Thornthwaite then moved the sprinkler 200 yards northward into a wooded area which had not been farmed for many years and was astonished when the area did not flood after 8 inches of application. The application was repeated daily for several days with the same result. Finally, after 48 hours of continuous irrigation at the rate of 1 in./hr, ponding occurred, but the ponds disappeared after a few hours' resting.

During the winter and spring of 1950, the Seabrook system was constructed to occupy wooded areas adjacent to the experimental tract. Initially, there were 72 sprinkler locations--each designed to receive 8 in./day. Each sprinkler covered a little over an acre, and water was applied at approximately 300 gpm. Later 12 more sprinkler locations were added when some areas did not perform as well as expected.

At the outset 76 test wells were installed and monitored for groundwater pollution. It soon became evident that the water quality was well within the United States Public Health Standards. Nitrate, for example, was never higher than 10 mg/L (2.2 as N). The monitoring program was discontinued after about 3 years. The test wells also enable investigators to plot the movement of groundwater and led to the publication of several papers on groundwater hydrology.

For at least 8 years and probably longer, the original design concepts were followed, i.e., 8 in./day during periods of stress and lesser quantities when factory production diminished. Meanwhile, a rigorous water economy program reduced the peak flow from 14.0 mgd to about 12.0 mgd.

The soils of the Seabrook treatment site lie within the Sassafras soil formation and are generally sandy in character. However, within the spray area, the silt and clay content is extremely low, resulting in a very low water retention capacity. Therefore, the land has low agricultural value and for this reason was abandoned to forest many years ago.

In 1950 the trees were largely oaks with a few cedars, ironwood, gum, and dogwood scattered amongst them. The growth was sparse and scrawny with large trees only in the low areas where water was available. Clearly this vegetation was thoroughly acclimated to the poor soil and was able to survive long periods of severe drought. It just barely missed becoming a grassland area similar to the Quinipiac Valley in Connecticut where glacial outwash deposited several feet of sterile sand. It was obvious from the outset that these deep rooted upland oaks could not survive the application of large quantities of water which drowned the zone of aeration. Surprisingly, however, the trees have survived in areas immediately adjacent to the sprinkler circle, indicating very little lateral movement of water near the soil surface.

Nothing has ever been done at Seabrook to alter the natural ecological succession, and observations over the years indicate that the flora and fauna have now stabilized in their new environment. During the first few years while the trees were dying, a weed known as Lambs Quarters grew to gigantic proportions. Gradually, this growth was replaced by smart weed, chick weed, blackberries, wild currant, and wild roses. The dominant species now is marsh grass of a variety that grows to a height of 10 feet or more in the low lands of New Jersey--very decidedly a foreigner to these upland soils of the spray area. It is also noted that the vegetative litter on the soil surface has ceased to accumulate, indicating that the rate of production is now matched by the rate of degradation.

The water for the Seabrook factory is pumped from 14 deep (150-foot) wells, all located within an area of less than one-half section. After being discharged from the factory, the water flows by gravity to a screening station where small pieces of vegetables are removed on vibrating screens. From there the water flows to a lift station and thence into a canal which conveys it 1.7 miles to the disposal site. The capacity of the canal is 3.0 million gallons and provides the treatment system with adequate surge capacity. Located along the canal are two major pumping stations which remove water during the summer for the irrigation of vegetable crops. (Since there is zero input of pathogens or residue of an animal nature, there is no constraint upon the use of this water for this purpose.) Downstream from the field irrigation pumping stations are seven 100-hp pumps which supply the treatment area. These discharge into 8-inch steel force mains which, in turn, break down to 4-inch laterals to supply each nozzle.

Hydrological studies during the early 1950s showed that the water applied to the treatment area flowed underground in a general southwesterly direction. It probably emerges as springs and seeps in the watershed of the Cohansey River. Because of this southwesterly flow, it is highly unlikely that any of the treated water finds its way northeasterly to the well field that supplies the factory. Therefore, the only reuse that can be claimed is the relatively small quantity withdrawn from the canal for crop irrigation.

In the early 1950s there was a complete shutdown of the factory during winter and the treatment area received no water. Around 1953 the winter processing of potatoes made it necessary to operate the system during weather that occasionally dropped to below zero. At first there was apprehension that the surface piping could not survive under these extreme conditions and that wastewater would flow into the streams over the frozen soil if there was a sudden thaw.

The problem was solved by disconnecting all but three sprinklers on each operating line and operating these continuously as long as the weather remained cold. This technique caused the formation of huge blocks of ice within the sprinkler pattern. When warm weather returned the ice melted slowly from the bottom up and gradually percolated into the soil. No overland runoff has been experienced.

Aside from the continuing high performance which many predicted would be exhausted by now, the most significant change in the system has been an alteration of the soil structure. One can only speculate as to what has happened, but it is very evident that the soil has become even more permeable than it was in 1950.

As mentioned previously, standard operation initially called for the application of 8 in./day at the rate of 1.0 in./hr during peak flow periods. Careful scheduling was maintained during periods of less than peak flow so that each area was given opportunity to rest and recover to be ready to accept the next increment of heavy flow. In 1973 the operating time has been extended to 12 hr/day, and even more important, there is no attempt to distribute the flow evenly throughout the tract. That is, when production falls off the areas most distant from the control house are not used, and the nearby sprinklers continue to receive the 12 inches per application. Thus, in theory, a single sprinkler might receive as much as 350 acre-ft/yr which closely approaches the loading rate of percolation beds at Flushing Meadows, Arizona. Quite obviously this change in operation has brought about a substantial saving in labor.

The piping and sprinkler arrangement has not been significantly altered in 20 years, and there has been no attempt to automate the controls. In fact, the labor cost of operation is so low that automatic controls would only be a convenience and could not be justified by a savings in labor.

The annual operating cost is on the order of $60,000 which reduces to 4.8¢/1,000 gal. It should be pointed out, however, that because of the seasonal nature of the Seabrook operation, the flow from the factory on a year-round basis is only 30 percent of the designed capacity of the treatment system. That is, if the flow were a uniform 10 or 12 mgd, the cost of treatment would be significantly less.

Three or four years ago a rumor was being circulated among local residents that Seabrook was responsible for the eutrophication of a downstream lake. And there was suspicion that the phosphorus adsorption capacity of the Seabrook treatment system had been finally exhausted. Accordingly, 10 new test wells were installed and samples were collected. Although the specific results of sample analysis are not available, the company has let it be known that the phosphorus removal is nearly complete, and that there has been no change in the groundwater quality since the sampling program of 20 years ago.

The waste treatment system of Seabrook Farms Company, after 23 years of operation, continues to achieve a very high degree of water purification. Quite contrary to early predictions the system has lost none of its treatment efficiency and has, in fact, improved. The original vegetation within the sprinkler pattern has been replaced by species that are ideally adapted to the environment. The Seabrook system has become an outstanding example of perfection in ecological succession.

Sebastopol, California

Industrial wastewater from five relatively small canneries processing apples and cherries is applied to the land by spray irrigation. The average flow is 0.3 mgd.

The soil in the 54-acre site is a clay loam. The application rate is 1.2 in./day, with 7 days of resting or an average loading rate of about 1.2 in./wk. Pretreatment consists of screening through a 10-mesh rotary drum screen. Sprinklers are spaced in a rectangular 50- by 60-foot grid. The 3/16-inch nozzles with nylon openings discharge 7.8 gpm at 60 psi. Laterals are 2-inch polyvinylchloride.

The wastewater characteristics are BOD, 1,800 to 3,000 mg/L; suspended solids, 75 to 160 mg/L; and pH 4 to 6.

The operation began in July 1972 without the drum screen in place. The screen had a capital cost of $6,500. The 54 acres cost $44,150 with site preparation of $2,700. Transmission for 15,000 feet with a crossing of Laguna de Santa Rosa cost $46,900, and distribution cost $32,000. Operation cost is estimated at $3,400 per year.

Tri/Valley Growers, Stockton, California

The Tri/Valley plant north of Stockton is a cannery that processes tomatoes, asparagus, carrots, and brine cherries on a seasonal basis. Approximately 3 mgd of wastewater is spray irrigated on 90 acres of heavy clay loam. The loading rate of 1.2 in./day is excessive, and a mosquito propagation problem, similar to the one at California Canners & Growers, has occurred.

The sprinkler systems consist of portable aluminum, 16-inch diameter mains and 4-inch diameter laterals. Screening of the wastewater is done within the plant, and the pump discharge lines are equipped with in-line screens. The wastewater is applied successively to each of nine 10-acre sections for 3 hours at a time. As indicated, the application is excessive and ponding occurs. Runoff flows back to the holding pond. It is repumped into the pond and eventually resprayed onto the fields.

As with California Canners & Growers, Tri/Valley intends to expand its system for 1973. An additional 75 acres has been purchased for expansion.

SITES VISITED BY APWA

The American Public Works Association in 1972 conducted a field survey of 100 facilities using land application of municipal and industrial wastewaters. Interviews could not be held at some facilities; however, there were 82 facilities to which on-site visits were made, and the data were presented in APWA's "Survey of Facilities Using Land Application of Wastewater," published by the EPA in 1973. The 82 sites are listed in Table 32. Ten other sites were visited, but the data were not included in APWA's report. These 10 sites are listed in Table 33.

Additional data were gathered by APWA for many existing facilities by means of a mail survey. In response to this survey 78 cities and 36 industries, listed in Table 34, provided data to APWA.

Table 32. Land Application Facilities On-Site Visits by APWA

No.	Agency and State	No.	Agency and State
	A. MUNICIPAL		
	ARIZONA		
1	City of Casa Grande	17	Irvine Ranch Water Dist., Irvine
2	Lake Havasu San. District, Lake Havasu	18	City of Oceanside
3	City of Mesa	19	City of Ontario
4	City of Prescott	20	City of Pleasanton
5	City of Tucson	21	City of Santa Maria
	CALIFORNIA	22	City of San Bernardino
6	Las Virgenes Municipal Water District, Los Angeles	23	Santee County Water Dist., San Diego
		24	City of San Clemente
7	Camarillo San. District, Camarillo	25	City of San Luis Obispo
		26	City of Ventura
8	City of Colton		COLORADO
9	City of Dinuba		
		27	City of Colorado Springs
10	City of Fontana		FLORIDA
11	City of Fresno		
12	City of Hanford	28	Walt Disney World
13	Valley Sanitation District	29	Oskaloosa County Water and Sewer District Eglin Air Force Base
14	Rossmoor Sanitation, Inc.,Laguna Hills	30	City of St.Petersburg
		31	City of Tallahassee
15	City of Livermore		MARYLAND
16	City of Lodi		
		32	St. Charles Utilities, Inc., St. Charles

Table 32. (Continued)

No.	Agency and State
	NEW JERSEY
33	Forsgate Sanitation, Inc., Cranbury
34	City of Vineland
	NEW MEXICO
35	City of Alamogordo
36	City of Clovis
37	City of Raton
38	City of Roswell
39	City of Santa Fe Silver Road Plant
40	City of Santa Fe Airport Road Plant
	NEVADA
41	Clark County
42	City of Ely
43	Incline Village
44	City of Las Vegas
	OKLAHOMA
45	City of Duncan
	OREGON
46	Unified Sewerage Agency, Forest Grove
47	City of Hillsboro
48	City of Milton-Freewater
	PENNSYLVANIA
49	Pennsylvania State U. State College-University Park
	TEXAS
50	City of Dumas
51	City of Kingsville
52	City of LaMesa
53	City of Midland
54	City of Monahans
55	City of San Angelo
56	City of Uvalde
	WASHINGTON
57	City of Ephrata
58	Town of Quincy
59	City of Walla Walla
	WYOMING
60	City of Cheyenne
61	City of Rawlins
	MEXICO
62	Mexico City, dry weather flow, treated
63	Mexico City, dry weather flow, raw

Table 32. (Concluded)

No.	Name, City, and State	No.	Name, City, and State
	B. INDUSTRIAL		
1i	Green Giant Company Buhl, Idaho	13i	Hunt-Wesson Foods, Inc. Bridgeton, New Jersey
2i	Western Farmers Assoc. Aberdeen, Idaho	14i	U. S. Gypsum Company Pilot Rock, Oregon
3i	Celotex Corporation Largo, Indiana	15i	Weyerhauser Company Springfield, Oregon
4i	Commercial Solvents Terre Haute, Indiana	16i	Pet Milk Company Biglerville, Pennsylvania
5i	Chesapeake Foods Cordova, Maryland	17i	Howes Leather Company Frank, West Virginia
6i	Celotex Corporation L'Anse, Michigan	18i	American Stores Dairy Company, Fairwater, Wisconsin
7i	Gerber Products Co. Fremont, Michigan	19i	Libby, McNeill & Libby Janesville, Wisconsin
8i	Michigan Milk Producers Assoc., Ovid, Michigan		
9i	Simpson Lee Paper Co. Vicksburg, Michigan		
10i	Green Giant Company Montgomery, Minnesota		
11i	Stokely Van Camp Fairmont, Minnesota		
12i	H.J.Heinz Company Salem, New Jersey		

Table 33. Facilities Visited by APWA, Data Not Tabulated

No.	Name	Reason
1	Barstow, California	Irrigate only sewage treatment plant grounds
2	Madera, California	Infiltration-percolation
3	Porterville, California	Infiltration-percolation
4	Visalia, California	Flow discharged to ditch All flow used by abutting property owner
5.	Whittier Narrows, California	Infiltration-percolation
6	Yuba City, California	Infiltration-percolation
7	Nantucket, Massachusetts	Infiltration-percolation
8	Scituate, Massachusetts	Infiltration-percolation
9	Gallup, New Mexico	Facility abandoned
10	Hobbs, New Mexico	Facility abandoned

Table 34. Responses to Mail Survey by APWA

No.	Agency and State
	A. MUNICIPAL
	ARIZONA
1	City of Winslow, WW Plant
	CALIFORNIA
2	City of Banning
3	City of Brentwood
4	Buellton Comm. Dist.
5	City of Corning
6	City of Corcoran
7	Co. Dept. of Honor Camps
8	Cutler Public Utilities Dist.
9	City of Dixon
10	City of Elsinore
11	Dept.of Parks & Rec. San Diego
12	Eastern Mun. Water Dist., San Jacinto
13	City of Escalon
14	Fallbrook Sanitary District
15	City of Greenfield
16	City of Gridley
17	City of Hanford
18	City of Healdsburg
19	City of Kerman
20	City of Kingsburg
21	City of Leucadia
22	City of Loyalton
23	City of Patterson
24	City of Pinedale
25	City of Pixley
26	Pomerado Co. Water District
27	City of Paso Robles
28	City of Reedley
29	City of Ripon
30	City of Riverbank
31	City of Riverside
32	San Bernardino County Special Districts Div.
33	San Juan Bautista
34	City of Santa Paula
35	City of Santa Rosa
36	City of Soledad

Table 34. (Continued)

No.	Agency and State	No.	Agency and State
	CALIFORNIA	53	Village of Middleville
37	Strathmore Pub. Util. Dist.	54	Ottawa County, Co. Road Commission
38	Terra Bella Sewer Main. Dist.		MONTANA
39	City of Tipton	55	City of Helena
40	City of Tulare	56	City of West Yellowstone
41	City of Tuolumne		NEBRASKA
42	Valley Center Munic. Water District	57	City of Grant
			NEVADA
43	Waterford Comm.Serv. District	58	City of Winnemucca
44	Westwood Comm. Serv. District		NEW MEXICO
		59	City of Lovington
45	Wheatland Dept. of Public Works		NORTH DAKOTA
46	City of Woodland	60	City of Dickinson
	KANSAS		OKLAHOMA
47	City of Scott City	61	Boise City
48	City of Sublette		OREGON
	MICHIGAN	62	City of Bend
49	Village of Cassopolis		TEXAS
50	City of East Jordan	63	City of Cotulla
51	Harbor Springs Area, Sewage Disposal Auth.	64	City of Coleman
		65	City of Comanche
52	City of Harrison	66	City of Dalhart

Table 34. (Continued)

No.	Agency and State	No.	Agency and State
	TEXAS	73	City of Ralls
67	City of Denver City	74	City of San Saba
68	City of Elsa	75	City of Seagraves
69	City of Goldthwaite	76	City of Van Horn
70	City of Idalou	77	City of Winters
71	City of Morton		WASHINGTON
72	City of Munday	78	City of Soap Lake

B. INDUSTRY

No.	Name, City, and State
1	Beardmore, Div. of Can Packers, Acton, Ontario, Canada
2	Simpson Lee Paper Co. Redding, California
3	Joan of Arc Company (Princeville-Peoria) Illinois
4	Joan of Arc Company (Hoopeston-Vermilion) Illinois
5	Green Giant Company Belvidere, Illinois
6	Campbell Soup Company Saratoga, Indiana
7	Popejoy Poultry Logansport, Indiana
8	Weston Paper & Mfg.Co. Terre Haute, Indiana
9	Albany Cheese, Inc. Grayson, Kentucky
10	Duffy-Mott Co., Inc. Hartford, Michigan
11	Simpson Lee Paper Co. Kalamazoo, Michigan
12	Green Giant Company Blue Earth, Minnesota
13	Green Giant Company Cokato, Minnesota
14	Green Giant Company Winsted, Minnesota
15	Borden Co., Comstock Foods, Waterloo, New York
16	H.P.Cannon & Sons,Inc. Dunn, North Carolina
17	The Beckman & Gast Co. Mercer, Ohio
18	Crown Zellerbach Baltimore, Ohio
19	Deeds Bros.Dairy, Inc. Lancaster, Ohio
20	Libby, McNeill & Libby Liepsic, Ohio

Table 34. (Concluded)

No.	Name, City, and State	No.	Name, City, and State
21	Sharp Canning, Inc. Rockford, Ohio	29	Green Giant Co. Ripon, Wisconsin
22	Campbell Soup Co. Paris, Texas	30	Green Giant Co. Rosendale, Wisconsin
23	Tooele City Corp. Tooele, Utah	31	Hoffman Corners Coop Creamery Kendall, Wisconsin
24	Lamb-Weston Div. of Amfac Connell, Washington	32	Kansas City Star Co. Park Falls, Wisconsin
25	Alto Coop Creamery Astico, Wisconsin	33	Kimberley Clark Niagara, Wisconsin
26	Cobb Canning Co. Cobb, Wisconsin	34	Loyal Canning Co. Loyal, Wisconsin
27	Frigo Cheese Corp. Wyocena, Wisconsin	35	Mammoth Spring Canning Oakfield, Wisconsin
28	Green Giant Co. Fox Lake, Wisconsin	36	Oconomowoc Canning Co. Sun Prairie, Wisconsin

APPENDIX B

HISTORICAL CASES OF IRRIGATION ABANDONMENT

To assess the state-of-the-art of land application, an analysis of reasons for abandonment of systems may add some insights. As irrigation has been practiced throughout the country for nearly 100 years, irrigation abandonment was chosen as a subject for selective inquiries.

INQUIRY DESIGN

On the basis of a 1934 survey by Hutchins [47] which he updated in 1937, a list was compiled of 121 cities in 15 western states that use irrigation. The list included 68 cities in California and Texas where wastewater used for irrigation was taken directly from outfalls or treatment plants, or where effluent was discharged to a stream channel and later diverted for irrigation. This list of 68 cities was compared to the 1972 Municipal Wastewater Treatment Plant Inventory compiled by EPA, and a list of 24 cities that had apparently ceased irrigating was compiled. This list formed the basis for inquiries as to the time, conditions, and reasons involved in irrigation abandonment.

INQUIRY RESULTS

Results of inquiries are given in narrative form for the cities which had actually ended the practice of wastewater irrigation. Of the total of 24 checked, it was found that 2 in California, Pomona and Susanville, and 2 in Texas, Canyon and Plainview, were actually continuing their operations.

California Sites

In general the 13 systems in California were abandoned because of the tremendous population growth over the intervening 35 years. Treatment plants became overloaded and had to be expanded and, in many instances, also relocated.

Agricultural lands near the cities were absorbed into the growing suburbs. In 1949 the State Public Health Department [99] promulgated regulations abolishing the practice of irrigation with untreated sewage and defining the quality of effluent acceptable for irrigation of various types of crops. This action led to upgraded pretreatment in most cases but abandonment of irrigation in others.

Cloverdale, California – A sewage farm was being operated at Cloverdale in 1933 with 2.5 acres of pears, 3.5 acres of vineyards, and 1.5 acres of fodder corn under irrigation. In 1949, because of the odors produced and the fact that untreated sewage irrigation was then declared illegal, the farm was abandoned. A residential area has since been developed on the site and a new treatment plant has been built.

Hemet, California – Crops grown at Hemet in 1933 included 100 acres of alfalfa, 30 acres of beet seed, and 10 acres of hay. Other crops irrigated over the years included milo, safflower, grain, and apricots, but the largest acreage was usually planted to alfalfa. Crops were irrigated by spraying and flooding with secondary effluent.

In 1966 the 0.6-mgd activated sludge plant, loaded at a rate of 0.85 mgd, was abandoned. The sewage from Hemet was discharged to the Eastern Municipal Water District for treatment. The effluent from the District is being recharged to groundwater, in part, and it is also being sold to farmers for irrigation water. At the time the plant was abandoned, 70 acres of City-owned land and 120 acres owned by an adjacent farmer were being irrigated successfully.

Kingsburg, California – Although not listed as a sewage farm in 1933, Hutchins reported (1937) that the wastewater at Kingsburg was being used to irrigate a vineyard. Apparently becauuse of the lye peeling wastewater discharged by Del Monte, the wastewater was deemed toxic as an irrigation water and the practice ceased. Presently, 0.5 mgd is being percolated on 110 acres of sandy soil. With the addition of the canning wastewater during the summer, the flow rates range from 2.2 mgd to 2.8 mgd.

Marysville, California – Until 1949, the sewage treatment at Marysville consisted of spreading untreated sewage on river bottom land. The silt-gravel percolation beds would be scarified every 3 to 4 days to keep the land from clogging. In 1933, 25 acres of dry beans were raised on the sewage farm. In 1949 the State Public Health Permit

System required at least primary treatment for all discharges into the Feather River and, in the case of Marysville, it prohibited direct discharge to the Feather River. The sewage treatment plant built in 1949 consisted of primary sedimentation followed by discharge to percolation ponds. Because the percolation ponds suffered from undue plugging, secondary treatment was installed in 1963. There are presently 40 acres of percolation ponds receiving a flow of approximately 1.7 mgd for an application rate of 11 in./wk.

Modesto, California – The history of sewage farming at Modesto has not been fully documented. Imhoff tanks were built in 1912, and the effluent was discharged to the Tuolumne River. In 1933, 78 acres of alfalfa, 60 acres of vineyards, and 20 acres of hay were being irrigated. In the mid-1940s this practice was replaced by oxidation ponds in series. The final pond served as a polishing pond for discharge to the river.

Two other entities, the Empire Sanitary District and the Beard Industrial Tract, used the land for wastewater irrigation in the 1940s and 1950s. The Beard Industrial Tract was expanded to nearly 500 acres in 1960. Both of these dischargers are now handled by the Modesto plant. Currently, treated effluent is piped 7 miles to some 1,000 acres of ponds on the San Joaquin River.

Orland, California – The City of Orland abandoned sewage irrigation in 1964. The old land disposal site consisted of 30 acres of pastureland. The reasons for abandonment were that the land was too close to the center of town and that the odors generated in the fields were obnoxious. The loading on the old land disposal site was 0.6 in./day or 4.3 in./wk. The present system consists of 60 acres of gravel beds for percolation and 60 acres of oxidation and storage ponds. This land is located 1.5 miles from town and is receiving an average of 0.5 mgd for an application rate of 2.1 in./wk. No attempt has been made to raise a crop on the 60 acres of percolation ponds at this time.

Pasadena, California – Pasadena operated one of the first sewage irrigation farms in the United States beginning in 1887. Originally, 300 acres were purchased at $125 per acre and, by 1914, 518 acres were owned. A septic tank was constructed in 1910, and concrete pipes were laid to distribute the sewage about the farm. The effluent was not allowed to run on any area of open ground longer than 4 to 10 days and, as soon as the land was dry, it was thoroughly cultivated and occasionally plowed. In 1914 the average application rate was about 1.0 in./wk, and the crops included alfalfa, walnuts, oranges, oats, field corn, pumpkins, sweet corn, and Kaffir corn. Growth of population in the farm vicinity led to complaints, and an activated sludge plant was built in 1924 [81]. In 1933, 75 acres of oranges, 125 acres of dry beans, and the remaining acre of grass, were being irrigated successfully.

The post-war urbanization in Los Angeles County forced changes in land use from agriculture to industry and suburban housing areas. In 1946, because of odor problems at the Tri-Cities Plant, Pasadena, South Pasadena, Alhambra, and San Marino joined the Los Angeles County Sanitation Districts. In 1948 the Tri-Cities Plant was demolished and the sewage was diverted to a District 16-trunk sewer [98].

Pomona, California - Sewage treatment at Pomona in 1930 consisted of an Imhoff tank followed by activated sludge. The effluent was being sold to the Northside Water Company for irrigation at $2.50 per acre-foot in winter and $5 per acre-foot in summer. During 1928-1929 the return from the sale of effluent was $4,669; the return from the sale of sludge, $414. The cost of operating the plant was $9,112, including $1,000 for chlorination [81].

In 1951 Pomona joined the Los Angeles County Sanitation Districts and the treatment plant was remodeled. Presently, about 12 percent of the effluent from the plant is purchased from LACSD by the City of Pomona for $7 per acre-foot. The City resells the effluent to various users for $5 to $22 per acre-foot. About 500 acres of citrus and forage crops are being irrigated.

St. Helena, California - The sewage treatment works at St. Helena from the turn of the century until 1967 consisted of septic tanks followed by discharge to ponds. Sewage irrigation was being practiced by nearby orchardists who could request an intermittent supply of effluent for irrigation. In 1933, 3 acres of sudan grass, 2 acres of prunes, and a 1-acre nursery were being irrigated. In 1967 the outdated sewage treatment plant was abandoned and a new site was developed south of the city. The new plant consisted of primary sedimentation followed by oxidation ponds with intermittent discharge to the Napa River. Sewage irrigation has ceased because of the change in location. No adverse environmental effects resulted from the sewage irrigation.

Susanville, California - The effluent from the Susanville sewage treatment plant is discharged to a ditch which runs approximately one-half mile before it is intercepted by irrigation ditches that supply wastewater to 5 ranchers.

There has been no abandonment of sewage irrigation during the summertime. Oxidation pond effluent is being used to raise hay, to irrigate pasturelands, and to water the stock. The plant flow is 0.8 mgd and between 500 and 600 acres of land are being irrigated. Currently, the rancher who is located nearest to the plant is complaining of the odors prevalent in the ditch which passes his land, and he has requested that a pipeline replace the ditch. During the wintertime the flow from the plant is discharged to the Susan River.

Ukiah, California - The effluent from the Ukiah sewage treatment plant was used to irrigate pear orchards until 1957. In that year, a new plant was built 4 miles from the original site. The pear growers merely shifted the source of their supply to the Russian River. In doing this, they avoided the requirement to halt irrigation within 30 days before harvesting. Presently, the effluent from the Ukiah sewage treatment plant is discharged to the Russian River. Previous crops irrigated at Ukiah included alfalfa and hops.

Vacaville, California - As reported in 1928 by Gillespie [39], septic tank effluent was being irrigated on 8 acres of grassland. The soil was tight, and 10 percent of the 30 million gallons applied over the summer at the rate of 0.125 mgd accumulated in ponds [81]. The slope was about 1.0 percent so that a form of overland flow was actually being used.

In 1933 the effluent was being used to irrigate an additional 36 acres of peaches, prunes, pears, and apricots. Around 1950 the practice was abandoned with the construction of the Brown Street sewage treatment plant. Today 5 mgd of wastewater receives secondary treatment prior to discharge to Cache Slough.

Whittier, California - The effluent from the Whittier treatment plant was used to irrigate 75 acres of alfalfa in 1933. A number of farmers and cattle ranchers used the treated water for pasture irrigation, in addition to alfalfa irrigation, and the water came at no expense. When the City of Whittier joined the Los Angeles County Sanitary Districts in 1948, Chief Engineer A. M. Rawn negotiated with these users in an attempt to sell the effluent and offset some of the costs for increased levels of treatment. The users refused to pay for the water and the sewage treatment plant was abandoned. The wastewater was incorporated into the District 18 treatment system [98].

Texas Sites

In Texas, the population increase has not influenced abandonment as heavily as it has in California. Reasons of nuisance, odors, plant relocation, management changes, and alternate sources of irrigation water were given for the 9 sites that were abandoned.

Baird, Texas – The wastewater from the Imhoff tank at Baird was used to irrigate a small garden area near the treatment plant until 1967. At that time a new trickling filter plant was built on the site of the garden. The City owns no more land in the area and discharges the 0.086 mgd of treated effluent, after chlorination, into a creek that is tributary to the Brazos River.

Breckenridge, Texas – The trickling filters built in 1922 have been upgraded to treat 0.3 mgd but need further enlargement. No information was received on when or why irrigation was abandoned.

Canyon, Texas – Primary effluent was being used for irrigation at Canyon until the 1950s. When a new sewage treatment plant was built, the old farm was abandoned and is now used as a city park. A trickling filter plant, followed by oxidation ponds, was built at a different location. During the summer months approximately two-thirds of the 1.2-mgd effluent is sold to a farmer for irrigation of 850 acres. During the other months of the year the effluent is discharged to a Tierra Blanca tributary stream. There has been no abandonment of wastewater irrigation although the original farm has been abandoned.

Childress, Texas – Irrigation with Imhoff tank effluent began at Childress around 1925. The effluent would flow in an open ditch until it was pumped out for irrigation on 150 acres by a nearby farmer. When the farmer was not irrigating, the flow in the ditch continued downstream and served as a source of drinking water for cattle. This periodic withdrawal led to stagnant ponds in the ditch and numerous odor complaints. In 1952 the practice of discharging to this dry channel was discontinued because of the odor complaints. Presently, the trickling filter effluent, amounting to 0.58 mgd, is discharged to Trosbecks Creek.

Georgetown, Texas – Irrigation of a pecan orchard near the city of Georgetown with primary effluent was discontinued in 1965. Reasons given for the abandonment were odor production and mosquito propagation. The loading rate at the time of abandonment was 7,000 gad. At present the 0.45 mgd is receiving activated sludge treatment with river discharge.

Mission, Texas - Mission is located in southern Texas about 4 miles from the Rio Grande. An Imhoff tank built in 1926 served as the treatment works with discharge to a floodway drainage ditch. In 1938 a farmer began pumping the effluent out of the ditch to irrigate small grain for cattle feed. After 2 years of operation a flood washed out the pump intake pool and created a new channel a considerable distance away. Because the effluent contained 600 to 700 mg/L of TDS, and there seemed to be abundance of irrigation water in the Rio Grande valley, the practice of sewage irrigation was never continued.

Plainview, Texas - There has been no abandonment of wastewater irrigation at Plainview. The practice began in the early 1930s when Imhoff tank effluent was discharged down a dry channel. Farmers adjacent to the channel would pump the effluent and use it for irrigation on a voluntary basis. When no users pump out the water it travels 6 to 8 miles before it finally infiltrates into the ground. The practice has not changed today although the plant now consists of trickling filters.

Robstown, Texas - Presently, Robstown discharges 0.7 mgd of activated sludge effluent to Ogo Creek. As recently as 1970 a portion of the effluent was used to irrigate turf grass. No reasons for abandonment were given.

San Marcos, Texas - Effluent from the treatment works at San Marcos has never been used for irrigation. The use referred to by Hutchins was a temporary application with liquid sludge for fertilizer. The sludge drying beds were overloaded, and the excess sludge was applied to the land until about 1950.

The effluent disposal system for 1.2 mgd from the larger of the two treatment plants is designed so that the effluent can be bypassed to irrigate adjacent property. Presently, the owner of the property feels that the flow is too small for him to consider converting his irrigation system.

Stamford, Texas - Effluent from the treatment works at Stamford was used to irrigate grain sorghum until 1945. The City Superintendent of Water and Sewers leased 15 acres from the City and operated the farm. When he retired in 1945 the practice was abandoned. Presently, an oxidation ditch is being constructed at Stamford, and the planned use of the effluent is for irrigation.

Stephenville, Texas – Presently, 0.5 mgd of stabilization pond effluent is being discharged to the Bosque River. No reasons for irrigation abandonment were given although abandonment probably occurred prior to 1950.

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SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

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WASTEWATER TREATMENT AND REUSE
BY LAND APPLICATION - **VOLUME II**

Pound, C. E., and Crites, R. W.

Metcalf & Eddy, Inc.
Palo Alto, California

68-01-0741

Environmental Protection Agency report number, EPA-660/2-73-006b, August 1973.

A nationwide study was conducted of the current knowledge and techniques of land application of municipal treatment plant effluents and industrial wastewaters. Selected sites were visited and extensive literature reviews were made (annotated bibliography will be published separately). Information and data were gathered on the many factors involved in system design and operation for the three major land application approaches: irrigation, overland flow, and infiltration-percolation. In addition, evaluations were made of environmental effects, public health considerations, and costs--areas in which limited data are available. Irrigation is the most reliable land application technique with respect to long term use and removal of pollutants from the wastewater. It is sufficiently developed so that general design and operational guidelines can be prepared from current technology. Overland flow was found to be an effective technique for industrial wastewater treatment. Further development is required to utilize its considerable potential for municipal wastewater tre[illegible] Infiltration-percolation is also a feasible method of land application. Criteria for site selection, groundwater control, and management techniques for high rate systems need further development.

*Irrigation systems, *Design criteria, *Wastewater treatment, *Costs, *Groundwater recharge, *Public health, *Environmental effects, *Sewage treatment, *Industrial wastes, Climatic zones, Reclaimed water, Wastewater disposal, Soil treatment, History, Crops, Percolation

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